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ASSET SUITABILITY ASSESSMENT IN SUPPORT OF OFFENSIVE MINING OPERATIONS

by

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Grant Rodgers, and Samantha Sperry

December 2023

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The naval battlespace in 2023 is more complex, faster evolving, and has a more lethal armament than ever in world history. The U.S. Navy is facing these challenges with a renewed emphasis on fleet lethality, long-range anti-ship cruise missiles, joint operations, and strategic alliances. In keeping with the objective of increasing fleet lethality, the Navy is re-exploring naval mining, something the U.S. Navy has not undertaken since the Vietnam War. This analysis uses discrete event modeling and simulation to assess the suitability of current and potential future naval mine deployment assets the U.S. Navy can use to realize its objective of fleet lethality. Team Trogdor assessed and compared the suitability of a B-52 bomber aircraft, a Littoral Combat Ship, a Virginia-Class submarine, and a Boeing extra-large unmanned underwater vehicle to determine and provide operational commanders and fleet operators with data to support the deployment of naval mines and recommendations for future acquisitions specific to mine warfare. Team Trogdor discovered the need for ships to be added to the nation's arsenal of mine deployment assets to meet the nation's needs ahead of pending hostilities with peer adversaries. This would include manning, training, and equipping the fleet with the capability to deploy naval mines from surface ships. In the words of Dr. Steven Willis of the Center for Maritime Strategy, "Mines are a joint force equalizer that the U.S. can no longer ignore."

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Grant Rodgers, and Samantha Sperry

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ABSTRACT

The naval battlespace in 2023 is more complex, faster evolving, and has a more lethal armament than ever in world history. The U.S. Navy is facing these challenges with a renewed emphasis on fleet lethality, long-range anti-ship cruise missiles, joint operations, and strategic alliances. In keeping with the objective of increasing fleet lethality, the Navy is re-exploring naval mining, something the U.S. Navy has not undertaken since the Vietnam War. This analysis uses discrete event modeling and simulation to assess the suitability of current and potential future naval mine deployment assets the U.S. Navy can use to realize its objective of fleet lethality. Team Trogdor assessed and compared the suitability of a B-52 bomber aircraft, a Littoral Combat Ship, a Virginia-Class submarine, and a Boeing extra-large unmanned underwater vehicle to determine and provide operational commanders and fleet operators with data to support the deployment of naval mines and recommendations for future acquisitions specific to mine warfare. Team Trogdor discovered the need for ships to be added to the nation's arsenal of mine deployment assets to meet the nation's needs ahead of pending hostilities with peer adversaries. This would include manning, training, and equipping the fleet with the capability to deploy naval mines from surface ships. In the words of Dr. Steven Willis of the Center for Maritime Strategy, "Mines are a joint force equalizer that the U.S. can no longer ignore."

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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LIST OF ACRONYMS AND ABBREVIATIONS

ALR	acceptable level of risk
AMW	amphibious warfare
ASW	anti-submarine warfare
C2	command and control
CDM	clandestine delivered mine
CG	Ticonderoga class cruiser
CJCS	Chairman of the Joint Chiefs of Staff
CNO	Chief of Naval Operations
DDG	guided missile destroyer
DOD	Department of Defense
DoE	design of experiments
DODAF	Department of Defense Architecture Framework
EOD	explosive ordnance disposal
FOB	forward operating base
FY	fiscal year
IED	improvised explosive device
IPR	in-progress review
LCS	Littoral Combat Ship
MIW	mine warfare
MoE	measure of effectiveness
MoP	measure of performance
MSSE	Masters of Science in Systems Engineering
NAWDC	Naval Advanced Warfighting Development Center
NPS	Naval Postgraduate School
NSM	Naval Strike Missile
NSWC	Naval Surface Warfare Center
NTTP	naval tactics techniques and procedures

P_d	probability of detection
Q1	quarter one
Q2	quarter two
R2B	return to base
RFA	request for analysis
RADM	rear admiral upper half (two-star)
RDML	rear admiral lower half (one-star)
RHIB	rigid-hull inflatable boat
ROE	rules of engagement
S&A	sea and anchor
SE	systems engineering
SLMM	submarine-launched mobile mine
SLOC	sea line of communication
SM	standard missile
SMWDC	Surface and Mine Warfighting Development Center
SUW	surface warfare
SWO	surface warfare officer
SysML	systems modeling language
TTP	tactics, techniques, and procedures
UUV	unmanned underwater vehicle
UWDC	Undersea Warfare Development Center
UXO	unexploded ordnance
WEZ	weapon engagement zone
WMD	weapons of mass destruction
WWI	World War One
WWII	World War Two
XLUUV	extra-large unmanned underwater vehicle

EXECUTIVE SUMMARY

The U.S. Navy has attained and maintained relative naval supremacy since its victory in World War II. Now, in 2023, its status as the premier worldwide naval power is being contested by peer adversaries who are developing technologies at a rate unseen in recent generations. With the rise in competition, the U.S. Navy has renewed its focus in fleet lethality through the purchase of new weapon systems, the advent of fleet warfare tactics instructors (WTIs) to train in these weapon systems, and placed emphasis on joint operations (Alexander 2021). With this emphasis on furthering fleet lethality comes the exploration of previously neglected warfare areas. Naval mines were used since the founding of the U.S.; however, since the Vietnam War, the U.S. has not employed naval mines offensively (Wills 2023). With this half a century of neglect, the capability of the U.S. to manufacture and deploy naval mines has diminished and cannot be ignored as an asset for warfare commanders to use in future naval conflict. This research explores current and potential future fleet asset suitability in the deployment of naval mines both to provide a planning tool for minefield planners to use in their endeavors to meet theatre-level fleet objectives and retain naval supremacy.

Team Trogdor conducted a literature review, exploring the historical employment of naval mines, the current mine deployment capability and fleet munitions inventory of the U.S. Navy, and ongoing efforts to augment the U.S.'s capability in the area of offensive mine employment. Team Trogdor then built a discrete-event model to account for the planning factors associated with deploying naval mines accounting for the variability of the dynamic environment in which the U.S. Navy operates. Team Trogdor finally ran four fleet assets (namely the B-52 Stratofortress, the Littoral Combat Ship, the Boeing extra-large unmanned underwater vehicle, and a Virginia-class nuclear-powered submarine) through the model to determine their ability to deliver naval mines in a timely manner while avoiding detection. We determined that the B-52 Stratofortress produced increased risk throughout the analysis due to an increased probability of detection. The Boeing XLUUV provided mines in theatre consistently but slowly while avoiding detections. The surface

ship provided a balance between the two both in terms of speed as well as their increased carrying capacity.

The U.S. Navy cannot afford to leave any asset unexplored in the deployment of naval mines. As it stands, there is currently no capability to deploy naval mines from surface ships. Aircraft are the only above-water asset that can deploy naval mines, namely the Quickstrike family of mines. The risk associated with this capability gap is that the Quickstrike family of mines can only be employed in 50 feet of water depth, which limits their ability to territorial waters, leaving the deploying aircraft vulnerable. Ships being outfitted with the ability to deploy naval mines both will allow the deployment of the hammerhead mine, but will also provide operational commanders with the ability to bring more munitions into the operating area, deploy them, and avoid detection.

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Alexander, Christopher. 2021. "About," Naval Surface and Mine Warfighting Development Center (SMWDC). May 17, 2021. https://www.surfpac.navy.mil/Ships/Naval-Surface-and-Mine-Warfighting-Development-Center-SMWDC/About/.

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Secondly to our advisors; Professors Beery and Paulo, and RDML (Ret.) Williams, thank you. With our constant questions, scope change, and misunderstandings (admittedly because we sometimes just didn't do the readings before we talked) your patience and guidance as we had to balance both our responsibilities to this assignment with those at home was both commendable and exactly what we needed.

Thirdly to the Navy and OPNAV N952 for offering us a worthy problem to solve. We feared that we would not spend our time and effort to a worthy cause, but as we move forward, we hope that the Navy will find our research useful and relevant to the challenges they face ahead. It is the fear of every human being that they are not useful, but we knew from the onset of this project that we had an opportunity to contend with a relevant problem. We are grateful for that.

Fourthly to our respective commands. You inevitably had to contend with the burden we placed upon you during our absence. Thank you for your understanding while we accomplished this task. It was not easy for anyone and shouldering our collective load while we undertook this has not gone unnoticed nor unappreciated.

Fifth and finally to one another. The distance-learning environment offers a unique series of challenges, and being constantly being accessible via Teams or some other medium leads to inevitable frustration. Thankfully we were all committed to delivering valuable research that could be of use to both our stakeholders and, more broadly, our

country. That started on day one. We all came in with varying levels of experience and with different skill sets. Each and every one of us was absolutely necessary to deliver this research and, Lord willing, make a tangible difference to our Navy's Sailors. Thank you!

I. INTRODUCTION

Team Trogdor is undertaking an exploratory analysis to develop new and refine existing mine deployment methods in the modern naval battlespace. This requires a review of the history of the Navy's use of mines, and the current tactics being employed by the U.S. Navy and their enemies. The team is conducting this analysis to determine how mines can be placed expeditiously and in keeping with commanders' intent and used as a force multiplier to shape the maritime battlespace.

Team Trogdor started this research with a literature review, an operational needs analysis, conducting modeling and simulation, and a suitability assessment for mine delivery platforms both individually and in concert with one another. We are implementing a "tailored vee" systems engineering (SE) approach to look at the battlefield and provide fleet recommendations based on individual asset mine deployment suitability.

Analysis is being done on the current mine inventory of the United States Navy and their deployment methods. The team investigates the current methods of deploying naval mines into the modern battlefield including the use of airborne, seaborne, undersea, and unmanned vehicle delivery methods. This investigation will provide data on the best way to deploy into friendly, neutral, and enemy waters. This investigation will not only show what current assets are capable of in today's battlespace but what configuration of assets would be necessary to complete all of the Navy's mine-laying objectives.

Our ultimate goal is to determine how to efficiently deploy mines while avoiding detection so other naval resources, such as ships and submarines, can focus their efforts on the destruction of enemy forces and lessen their need to patrol for enemy craft. Secondarily, the products developed by Team Trogdor can be used without the detection constraint to better determine the overt mine laying capabilities of the different platforms that are being researched.

A. BACKGROUND

History is rife with examples of the use of offensive mines and their disproportionate effects on adversary ships and merchant shipping. Entire economies can grind to a near-halt with the effective use of naval mines (Lott 1959). Despite these effects, since the use of naval mines during the Vietnam War, the use of naval mines has been removed from the national military strategy consciousness in favor of the high-end anti-ship cruise missile (ASCM) and anti-submarine warfare (ASW) threat (National Academy of Sciences 2001). While these threats present an urgent risk to force naval mines remain a ready-to-employ source of destructive power not only for state actors but non-state actors as well.

To contend with this capability gap, the U.S. Navy has renewed its focus on fleet lethality and its offensive mining capability. The Navy in 2015 founded the Surface and Mine Warfighting Development Center (SMWDC), a command focused on providing an interface between the engineering and warfighting communities to allow for emerging tactics to reflect technological advances and bringing both to the hands of the warfighter. The warfare tactics instructor (WTI) program established by SMWDC is the mechanism with which that focus is brought into reality. The program was modeled after the TOPGUN program provided by Naval Advanced Warfighting Development Center (NAWDC) wherein junior officers are trained to specialize in a warfare area and provide that specialized training to the fleet. The mine warfare (MIW) arm of that was founded in 2017 and has been providing fleet training since its inception. The U.S. has also deployed its first Boeing Orca extra-large unmanned underwater vehicle (XLUUV) in support of covert mine insertion (William Barnes, personal communication, July 31, 2023). Additional efforts include the hammerhead mine (the successor to the CAPTOR mine), the submarine-launched mobile mine (SLMM), and the clandestine delivered mine (CDM).

These acquisitions and efforts do present policy-makers and tacticians alike a daunting question: Will this be enough? As shown during the Northern Barrage in World War One (WWI), the use of naval mines requires sizable inventory to cover a large geographic area and with the increased inventory of naval mines, assets to deploy them in a modern battlespace. Covert insertion of mines that does not put the deploying asset at risk is preferred, but practically speaking, the assets available cannot covertly deliver the number of mines required (William Barnes, personal communication, July 31, 2023). In today's naval fleet there is currently no means to deploy mines off of surface ships. This lack of capability potentially creates a lack of flexibility in available assets for warfare commanders to employ to realize their intended effects on the naval battlefield. This analysis will explore real-world balance between covert deployment and inventory constraints as well as provide an objective analysis of deployment assets to promulgate acquisition requirements.

B. TEAM ORGANIZATION AND ANALYSIS

Team Trogdor is a team comprised of five individuals with varying levels of fleet, military-supporting, and operational experience.

Jason Pinnow is currently serving as a surface warfare officer (SWO) in the Navy. He works at SMWDC as a SUW/ASW WTI at SMWDC in the doctrine and tactics, techniques, and procedures (TTP) development branch. He has 2.5 years of fleet operational experience onboard USS NITZE (DDG-94) both as the operations intelligence divisional officer and the main propulsion division officer. He also served for 2.5 years onboard USS FORT WORTH (LCS-3) as the auxiliaries, main propulsion, and electrical officer wherein he oversaw the maintenance and operation of propulsion, auxiliaries, and electrical distribution equipment. Jason is a graduate student at Naval Postgraduate School in the Master of Sciences in SE (MSSE) program graduating in Q1 FY24.

Andrew Murray is currently working as a network engineer on the MK160 program at Naval Surface Warfare Center, Dahlgren Division. He has worked for over 20 years in the Information Technology field. Andrew is a graduate student at Naval Postgraduate School in the MSSE program graduating in quarter two (Q2) of fiscal year 2024 (FY24).

Samantha Sperry is the Naval Ordnance Safety and Security Activity Combat System Safety Branch Lead (N32) and is a Weapon Systems Explosive Safety Review Board (WSESRB) Point of Contact. She has over eleven years of system safety and SE experience supporting research, developmental, and large system of systems programs. Samantha is a graduate student at Naval Postgraduate School in the MSSE program graduating in Q1 FY24.

Grant Rodgers is working as an aerospace engineer for Naval Surface Warfare Center Dahlgren Division. He currently has 3 years of engineering experience working with Guidance, Navigation, and Control components of different systems and how they interface with the system as a whole. Grant is a graduate student at Naval Postgraduate School in the MSSE cohort, 311–222S, graduating in Q1 FY24.

John Holder is currently working at Naval Surface Warfare Center, Dahlgren Division as an Electrical Engineer for the MK134 program, spun off the MK38 Mod 4 project, as well as the Lead Electrical Engineer for the Rocket Weapons System (RWS) Feasibility Study, a Naval Innovative Science and Engineering (NISE) program. He also completed a detail as the Lead Systems Engineer for the Optical Dazzling Interdictor, Navy (ODIN) project. Academically, John is a graduate student at Naval Postgraduate School in the MSSE cohort, 311–222S, graduating in Q1 FY24.

1. Defining Project Scope

The team was initially presented with a problem set with a broad scope. The first request for analysis (RFA) was to look at MIW to provide analysis on mining and countermining and deployment assets. On 30 March 2023, the first meeting with academic advisors narrowed that scope to mining operations and how those could be leveraged by fleet operators to achieve strategic effects within the larger context of naval warfare. This drew the scope down to half of MIW.

The team initially promulgated a project plan consisting both of employment asset viability and operational employment of naval mines. Both of which were going to be modeled using Map Aware Non-Uniform Automata (MANA). MANA is an agent-based software developed by New Zealand to model land-based agents, but that was going to be translated to surface ships during three mining scenarios. The initial plan consisted of two distinct phases. The first phase would explore the viability and suitability of deployment assets on the battlefield and, with an agent-based software equipped with the ability to map geography, would have agents travel from FOBs to their drop locations and deploy their mine payloads. The second phase was to assess mine capabilities in three operational scenarios. The first scenario was using mines to shape the battlespace in a sea denial to dictate enemy action and cause enemy ships to move within the weapon engagement zone (WEZ) of a U.S. warship resulting in the attrition of the enemy warship. The second scenario was a more tactical scenario. The scenario dictated either a gunfight or harassing behavior on the part of the enemy where the enemy followed a U.S. ship into an existing (and undisclosed) minefield resulting in the enemy warship's attrition. The third scenario was a protective mining scenario. In this scenario, a minefield was placed to allow a greater stand-off distance on the part of U.S. surface platforms which placed the enemy in the horns of a dilemma. The dilemma being they would either maneuver into a minefield and potentially impact an allied mine or attempt to circumvent the minefield and maneuvering into the WEZ of a surface vessel capable of employing a standard missile (SM) or naval strike missile (NSM) and be successfully engaged.

The team presented this scenario during the first IPR and was the plan for the team. However, following input and direction from the primary stakeholders at OPNAV N952, the scope narrowed to focus on the suitability of deployment assets before wartime. The scenarios up until that point presupposed those hostilities had already commenced, not in keeping with the stakeholder's intent. With that, the scope changed to solely focus on deployment assets during peacetime operations. Additionally, this shift in focus changed the team's modeling software. The team used a linear discrete-event modeling software called ExtendSim to model the discrete events pertaining to mine deployment and will assess their suitability based on time, P_d, munition inventory constraints, and reload time.

2. Scope

The scope of the project is to analyze the Navy's use of mines warfare in the past, examine the current mine inventory of the Navy, and generate a model to simulate the deployment of naval mines in a modern battlefield. This will include a suitability assessment of each deployment asset (surface ship, aircraft, submarine, XLUUV) individually followed by a regression analysis to provide fleet commanders with insight into the assets required to deploy naval mines in pursuit of their mission objectives in keeping with their commander's intent.

3. Objectives

The objectives of the project are twofold. The first phase of simulations will determine the operational suitability of mine deployment assets. This will come in the form of analyzing the four current mine deployment assets to determine their respective performance in a contested environment. The second phase of simulations will be to use the data extrapolated from the previous analysis to provide insight and analysis into the quantity of each deployment asset required to meet an assigned mission. This analysis will include a final report with tools and analyses for mission planners to use to plan mine deployment missions and meet their objectives.

4. Constraints

This project is written and simulated primarily at the unclassified level which will limit the model's ability to accurately reflect the real-world outcomes due to the lack of precise data inputs into the model.

Without being fully appraised of enemy threat detection capabilities, the accuracy of the probability of detection (P_d) coefficient in the model was based on fleet operational experience in part by the team and in part by the direction from the primary stakeholder.

Mine capacities for individual assets were based on open-source and military promulgated unclassified material. As such, their actual capacities may differ slightly from those used in the model. Additionally, the specific capacity for naval mines onboard surface ships had to be determined based on cargo space and displacement. There currently is no existing and approved method for deploying naval mines offensively from a surface ship. As such, the inventory and times were conjectured.

5. Stakeholders

a. Numbered Fleet Commanders

Numbered fleet commanders represent a primary customer for an efficient MIW employment methodology. Operational proficiency and efficiency in MIW during conflict represents an additional capability for maintaining control over fleet areas of responsibility (AORs).

b. U.S. Fleet Forces Command

The mission of U.S. Fleet Forces Command (USFF) is to "train, certify and provide combat-ready Navy forces to combatant commanders that can conduct prompt, sustained naval, joint and combined operations in support of U.S. national interests" (U.S. Navy 2023). With that mission and with the advent of a physical system or new tactics, training will have to be planned and executed by USFF for fleet employment.

c. Surface and Mine Warfighting Development Center

The Surface and Mine Warfighting Development Center's (SMWDC) mission is to "increase the tactical proficiency and lethality of the Surface Force across all domains" (Alexander 2021). SMWDC accomplishes this mission through; advanced tactical training, WTI production, doctrine and tactical guidance development in the form of Tactics Techniques and Procedures (TTP), operational support to Naval Component Commanders, Numbered Fleet Commanders, and Combatant Commanders, and conducts capability assessments, experimentation, and supports promulgates requirements for Navy acquisitions. With the advent of a mine deployment methodology or system, SMWDC will both have to promulgate the TTP for surface forces to reference as well as conduct training in the form of SWATT or other fleet exercises to ensure its effective employment.

d. Commanding Officers

A commanding officer (CO) whether of an aircraft squadron, a submarine, or surface ship is responsible for the accomplishment of assigned missions, maintenance and care of their craft, and the well-being of their personnel. As such, ensuring them and their crews are properly trained in the safe and effective use of mining capabilities will allow them to accomplish their missions, minimize their ship's P_d in contested water space, and return to home port.

e. OPNAV N952

LCDR Rolando Machado and LT William Barnes work as requirements officers for the MIW requirements branch (N952) at the Pentagon. As such, they represent the primary stakeholder. Team Trogdor leverages both LCDR Machado and LT Barnes in promulgating its needs and system requirements for analyses. They also provide both technical expertise in MIW, Fleet needs for MIW systems, and guidance for research efforts.

6. Project Team

Team Trogdor is comprised of five individuals; Andrew Murray, Jason Pinnow, Grant Rodgers, Samantha Sperry, and John Holder. All team members will be operationally proficient in the use of ExtendSim and Innoslate, linguistically proficient in U.S. fleet operations, and prepared to assist the rest of the team within their respective roles. Their individual roles within the SE process are:

a. Project Manager

Team Trogdor's project manager (Jason Pinnow) holds primary responsibility for promulgating project milestones, interaction with stakeholders, coordinating with Naval Postgraduate School (NPS) faculty, and serves as the lead editor for the project.

b. Systems Architect

Team Trogdor's systems architect (Samantha Sperry) manages and illustrates programmatic and system interfaces through Innoslate and oversees adherence to the promulgated SE (modified Vee) methodology.

c. Modeling and Simulation Engineer

The modeling and simulation engineer (Andrew Murray) holds primary control over the models Team Trogdor will use to conduct analysis. He will interface with the project manager and systems architect to create representative models and useful analysis.

d. Decision Analyst

The decision analyst (Grant Rodgers) will analyze data output from the ExtendSim and Innoslate models and determine the most operationally suitable deployment assets.

e. Requirements Developer/Analyst

The requirements developer/analyst (John Holder) is responsible for the promulgation of complete, realistic, and quantifiable system requirements for the project, overseeing/modifying those requirements as needed throughout the project, and promulgating fleet recommendations at the conclusion of research.

7. Collaborators/Advisors

a. Professors / Academic Advisors

Professor Paul Beery serves as the primary faculty advisor for the project.

Professor Eugene Paulo serves as an academic advisor for the project.

Richard Williams, RDML, USN (RET) serves as both an academic and technical advisor for the project.

8. Analysis Tools

The following outlines the tools and methods Team Trogdor will use to conduct both its systems architecture and design as well as conduct modeling and simulation in support of data analysis.

a. Data Collection

The primary means of data collection to support modeling and analysis are through an unclassified (UNCLAS) literature review, collaboration with the project sponsor, and data collections with subject matter experts within SMWDC, and fleet operators.

b. Data Analysis

ExtendSim is the primary modeling and simulation tool. ExtendSim is a discrete event modeling software capable of computing multi-variable analyses for discrete events and conducting Monte Carlo analyses to develop average values across thousands of simulation runs.

c. Reporting

The final report will be promulgated using MS Word, the In Progress Reviews (IPR) will be promulgated using MS PowerPoint, and the results of analysis will be given to NPS for future use in support of fleet operations.

9. Requirements Analysis

The system requirements were derived from stakeholder needs, military standards, and design requirements. All these design constraints will be discussed in the following sections.

a. Essential Design Requirements

Essential design requirements are those items Team Trogdor is expected to deliver and account for in the design of our model. These are to both keep both operational realism and real-world system constraints into account while populating the model for analysis.

- The model shall include officially known unclassified characteristics of U.S. Navy mine delivery assets.
- The model shall use time data to accurately record all aspects of the naval mining mission for analysis purposes.
- The model shall use vehicle mine capacity to simulate the maximum number of deployed mines in the area of operation given the vehicle type's characteristics.
- The model shall use one asset per type to determine the maximum number of mines deployed in the defined timeframe. This value can be scaled by the number of available assets of that type.
- Depth of delivery area: The deployable area where Quickstrike and hammerhead mines are effective based on location and depth shall be used to determine the number of mines required to provide blast coverage for the operating area.

- Covert delivery: The covert delivery of mines pre-conflict shall not be detected risking the provocation/escalation of war.

- Vehicle capacity: Each vehicle shall be supplied with the maximum number of mines based on the expected or estimated capacity from publicly available sources.

- Speed of delivery vehicle: Each vehicle's speed shall be estimated based off publicly available information and converted to hours with a fixed distance modelled.

- Time of day operations for covert status: The Destroyer and B-52 vehicles will be limited to nighttime operations, 1900 to 0600, to achieve the lowest P_d. The XLUUV and Submarine vehicles shall operate 24 hours per day.

b. Design Constraints

Design constraints are limitations placed on assets in the execution of their mission and those constraints that preclude absolute operational realism in the promulgation of the model.

- Covert Operations: Each deployment method in the model will be evaluated by the number of mines delivered while maintaining a covert or undetected status. In the event of detection, based on an estimated detection probability, that deployment method's simulation will end.

- Single vehicle type delivery: Each delivery vehicle; XLUUV, Submarine, Destroyer, and B-52, shall be independently simulated within the model and compared against one another to determine the effectiveness of the delivery methods.

- Linear modeling software: ExtendSim model and simulation software is a linear program using stochastic analysis of events along a specified time interval. As such, the number of mines deployed to achieve desired mining area, the vehicle is detected, and/or the time limit has been reached will end the simulation for each/all the delivery methods.

- Required number of mines: Each deployment simulation shall end when the assigned number of mines have been deployed meeting the required number of mines to cover 50 percent of the deployment area.
- Number of vehicles available: Each deployment method simulation will have type of asset vehicle running the mining operation until the simulation is ended.

c. *Assumptions*

When developing the model to simulate naval mine deployment, Team Trogdor needed to make several assumptions. These assumptions and the reasoning behind them are described in the following sections.

(1) Mines will be employed during peacetime conditions

Employing mines during this analysis will be conducted during peacetime (i.e., prior to the commencement of hostilities. This assumption is crucial for this particular study as it bounds the problem and provides context for the operational environment in which the deployment assets will be used. Title 10 requirements stipulate the requirement for nations to disclose the presence of an active minefield to protect merchant traffic (U.S. Government Printing Office 2011). The current interpretation of Title 10 suggests that minefields that are not active but are laid do not need to be disclosed to the international community (William Barnes, personal communication, July 31, 2023).

(2) Fully mission capable deployment assets

Deploying assets can remain fully mission-capable throughout mine deployment. Equipment casualties are common on ships during underway operations. Speed limitations resulting in the loss of a diesel engine (which, in the case of the LCS would result in a reduction in maximum speed available) would result in a variability in mine deployment speed (which cannot be accurately quantified outside of the individual deployment iteration). Therefore, the team will operate under the assumption that the deployment assets will always remain capable of maximum speed throughout their missions.

(3) Independently operating assets

No interaction between assets. These simulations will show data for one deployment asset at a time (i.e., one LCS, one Virginia-Class Submarine, one Boeing XLUUV, and one B-52 bomber aircraft). Each iteration will be an independent event. A single deploying asset will leave their forward operating base (FOB), transit to their respective operating areas, deploy their payload of mines, return to base, be outfitted with additional mines and sent back out. There is no interdependence between the aircraft, submarine (both unmanned and manned), or surface ships. This is to ensure the analysis is a fair assessment of their respective viabilities.

(4) No red force interference

The initial assumption that these evolutions will occur during peacetime leads to the additional assumption that red forces will not interfere with the missions being conducted by these deployment assets. These include harassment, shaping of the battlespace, etc.

(5) Effectiveness of individual deployment assets can be extrapolated to groups of assets

The effectiveness of each vehicle can be extrapolated to larger groups of deployment assets. The intent of the study is to show the viability of each deployment asset individually. However, with two ships, submarines, or aircraft deploying simultaneously or near simultaneously would result in either twice the number of mines being delivered during an assigned mission or that it will take half the time to deploy the same number of mines. This study does not explore a combined effort among multiple assets. This assumption simplifies analysis but potentially provides an additional decision-point for warfare commanders to consider during mine employment. After a multitude of runs throughout the simulation to determine individual asset suitability, a regression analysis will be conducted based on this data using JMP to determine how many assets would be required for a larger mission.

(6) Adherence to current ammunition-handling guidance

Current ammunition handling requirements will be adhered to during the in-port period (CNO 2018). These requirements are going to be upheld during the analysis in keeping with the first assumption of peacetime operations. This assumption informs the mean time between deployment variables of the model, which extends the timeframe in which deployment assets will be reloaded before starting additional missions.

(7) Nighttime mine deployment on surface and air deployment assets

Mine deployment from both surface ships and aircraft will occur during a six-hour time window at night. This will allow a lower P_d (or at the very least it will make the enemy question what the surface ships and aircraft are doing). In the instance of a surface ship, current Environmental Protection Association (EPA) guidelines dictate instances in which biodegradable material (i.e., food waste) can be discharged over the side of the ship at 12 nautical miles from shore (Naval Sea Systems Command 1999). This most often occurs in the night-time hours when ships are not making meals for the crew to maintain sanitary conditions and minimize food waste retained onboard. This occurs regularly and represents an everyday component of underway operations. This offers the opportunity for ambiguity and, in the case of naval mines, a means to avoid the enemy ascertaining what is taking place (meaning the enemy could see something going over the side and thinking it is a normal occurrence). This assumption serves multiple purposes. It allows a lower P_d for the surface ship. Also, it adds a realistic component to the analysis, taking human nature (in part of the enemy) into account during the analysis.

(8) All pier-support and ordnance handling support services are on time and on station prior to asset returning to base and departure.

When a ship pulls into and out of port, pier support services are required to bring them in. These include items like potable water, electrical, and sewage connections. In the case of the submarine and surface ship, these items are attached to the ship when it pulls into port (and subsequently detached when the ship is departing port). Additionally, to bring ammunition on board ships, ammunition handling requirements outlined by the Chief of Naval Operations dictates the need for qualified crane operators to handle explosive ordnance (CNO 2018). Coordination of these pier services is key to all outbound and inbound evolutions underway. These assets must be coordinated before a ship leaves and enters port to ensure timely arrivals and departures. However, this is not always the case in the event of human error. For this analysis, the team is operating under the assumption that a proficient operations officer is onboard the deploying asset (specifically in the case of the submarine and LCS) to facilitate timely departure, arrival, and munition on loads.

(9) Quick strike mines will only be employed by the B-52 aircraft

Current available technologies only avail the Quick strike mines to aircraft deployment, as such, the B-52 will be the only asset that will be modeled with the three variations of Quickstrike mines (William Barnes, personal communication, July 31, 2023). The three variants (Mk 62, Mk 63, and Mk 65) will be deployed from separate aircraft and a composite average will be derived from the analysis.

(10) Hammerhead mines will be employed by the submarine, LCS, and XLUUV.

Quickstrike mines are only available for deployment by aircraft. As such, for the sake of analysis, the hammerhead mine (the successor to the CAPTOR mine) will be deployed by the submarine and XLUUV in keeping with OPNAV N952's request for analysis into the ability to deploy the hammerhead mine (William Barnes, personal communication, July 31, 2023). Subsequently, hammerhead mines can only be deployed by surface and subsurface assets and not aircraft.

(11) No mixed loadouts will be modeled

Mine deployment assets can house a multitude of different mine types all varying in size, shape, and subsequent capacity. For the sake of modeling (and as an illustrative point to the reader) each asset will only be outfitted with one type of mine in its inventory.

(12) Operator proficiency and training on the part of the personnel onboard deploying assets is sufficient

Emerging technologies and user interfaces avail themselves to operator error, especially in MIW wherein the U.S. Navy currently lacks proficiency (Hendricks 2019). For this analysis, the assumption has been made that crews are both proficient and efficient at deploying mines.

(13) Mine deployment time is estimated

Alongside the assumption of operator proficiency, the team is operating under the assumption that mine deployment times are equivocal to the time required to put a rigid-hull inflatable boat (RHIB) into the water. While this is not a completely accurate assumption, it is the most analogous evolution that currently takes place on a surface ship that would mimic the amount of personnel and safety considerations required to place naval mines in the water from a surface ship. The rest of the deployment assets' times are estimated based on data derived from unclassified sources which will not be entirely accurate. Accurate data would have to be derived from SECRET sources which is beyond the classification level of this analysis.

(14) Requisite personnel and personnel qualifications are attained prior to commencement of mine deployment mission

Personnel constraints are a continual point of contention on ships and aircraft in the Navy. To employ weapon systems in keeping with the peacetime operations assumption, all qualifications will have to be attained prior to accomplishing an assigned mine deployment mission. For this analysis, it is assumed that prior to embarking on its mission the ships, aircraft, and submarines are fully qualified to deploy mines and are trained to employ them within the assigned timeframe.

10. Functional Analyses

The functional analysis was conducted to model and develop descriptive processes that reflect the system's functional and architectural structure and rules. Team Trogdor integrated data and artifacts to create one system description using Department of Defense

Architecture Framework (DODAF) and Systems Modeling Language (SysML). To start this process the team gathered data on current deployed systems and modeled from the broadest point of view to understand the operational considerations that are made when mines are deployed. As the team narrowed the system's point of view operational and system models were created and are discussed herein.

a. Operational Viewpoints

(1) OV-1: Operational Concept

Based on data gathered, the needs analysis, and the requirements analysis, an Operational Concept (OV-1) was developed. Depicted by Figure 1, the operational concept describes at a high level what and how the mine deployment system is supposed to be conducted. It also identifies system interactions, including external interactions.

For the Mine Deployment System, the team looked at protective mining operations to defend an allied island. A B-52, LCS, Virgina-Class Submarine, and/or UUV will be used to distribute Naval mines to provide additional defense and deter the enemies from conducting amphibious operations. The OV-1 displayed in Figure 1 provides a depiction of this.

For simplicity, mines in the OV-1 are not specific. The surface and subsurface assets will exclusively deploy the hammerhead mine. The airborne asset will exclusively deploy the Quickstrike family of mines. The deployed mines may communicate location, health, and status back to the platform that they were deployed from and then that platform would be responsible for further communicating the mine location, health, and status to the other fleet assets through the desired network architecture (e.g., LINK). In this concept the mines do not communicate with one another and communication between platforms and fleet assets is thought to occur through a network architecture such as LINK 16.

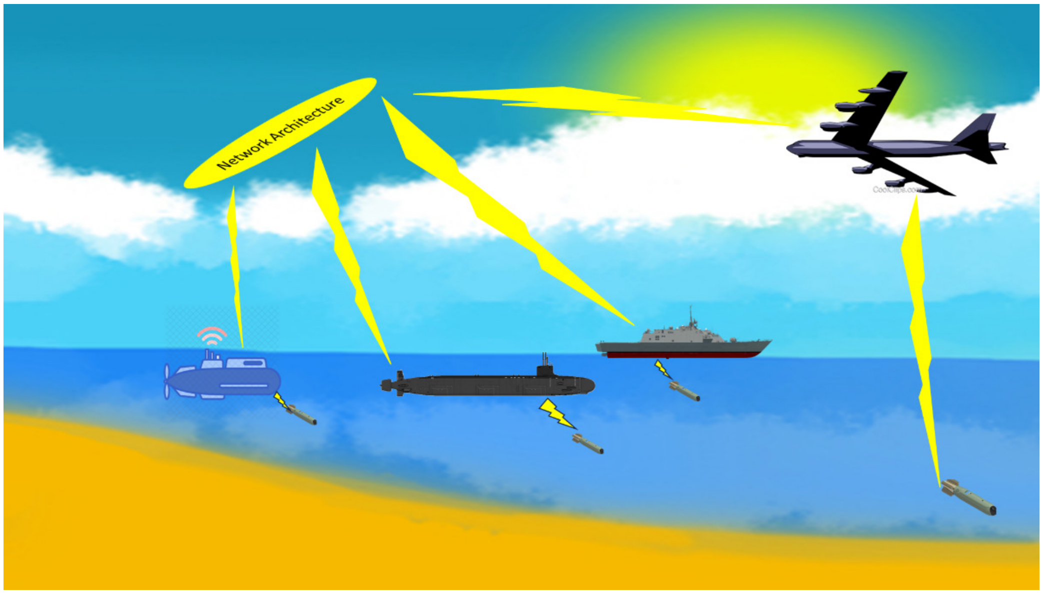

Figure 1. Mine Deployment Operational Concept (OV-1)

(2) OV-2: Operational Connectivity

Once the OV-1 was completed an Operational Node Connectivity (OV-2) diagram was constructed for mine deployment on ships, as displayed in Figure 2. The OV-2 indicates where information needs to be exchanged between operational elements and/or assets (referred to as need lines from hereon). The mine deployment system has multiple needlines with the mine deployment platform and overall asset having the majority of needlines.

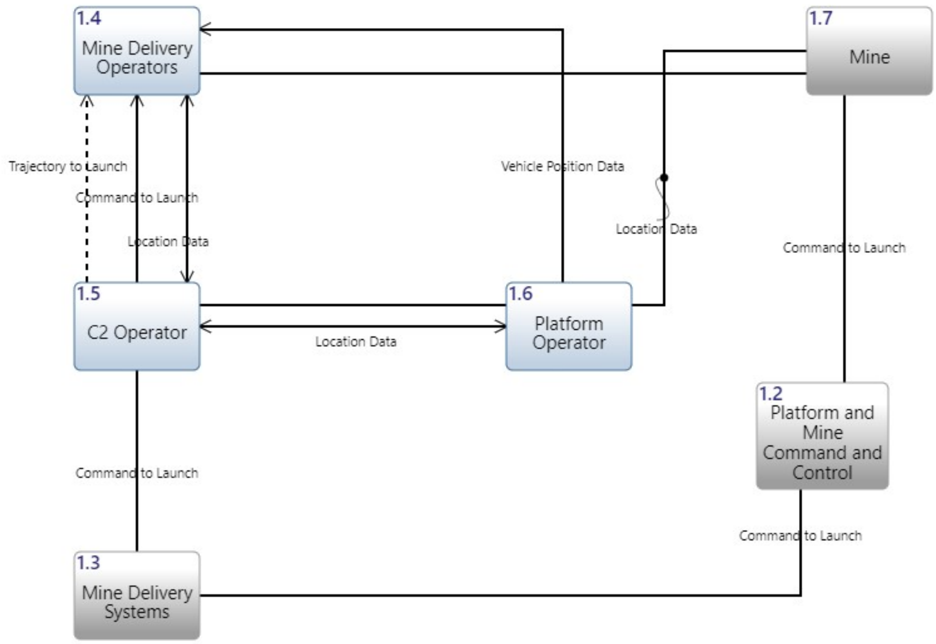

Figure 2. Operational Node Connectivity (OV-2)

b. System Viewpoints

(1) SV-1: Systems Interface Description

In conjunction with the OV-1 (Figure 1), a Systems Interface Diagram (SV-1) was developed. The SV-1 diagram (Figure 3) identifies the systems' functional subsystems and elements and can also identify cross organizational interfaces. The mine deployment system has four (4) systems with one (1) subsystem with multiple interfaces.

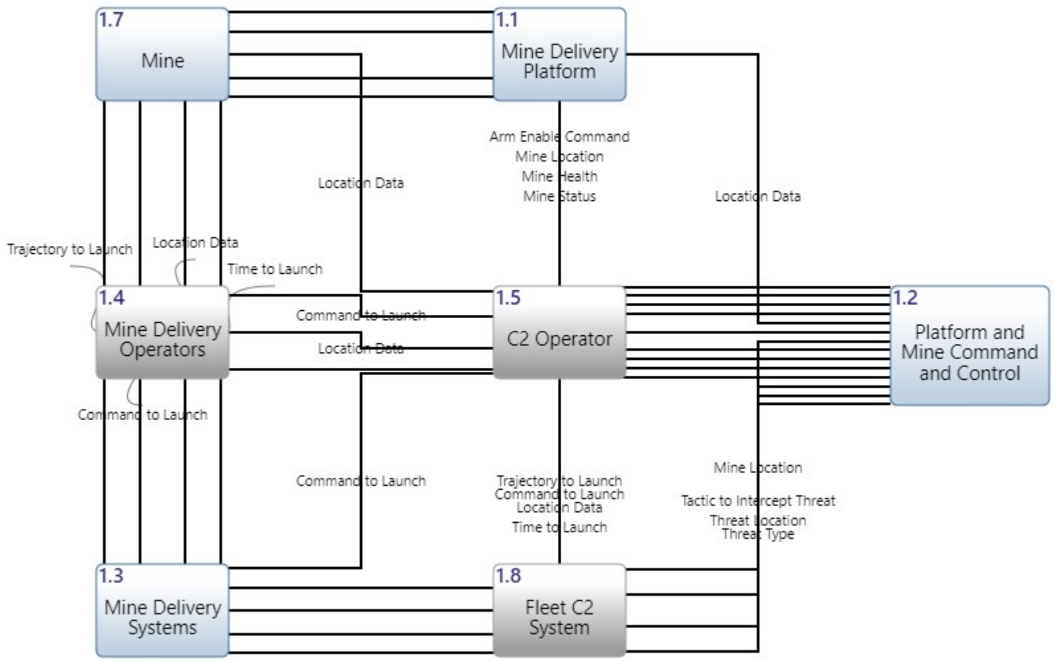

Figure 3. Systems Interface Diagram (SV-1)

11. Problem Statement and Research Questions

Team Trogdor is assessing four potential deployment assets and their use as mine layers in the modern naval battlespace. Specific questions that will be answered include:

- What scenarios are appropriate for employment of naval mines?
- What deployment methods provide adequate mine coverage during presupposed time and inventory constraints?
- What are the potential limitations created by the objective for fully covert peacetime minelaying?

The team will investigate deployment methods (both potential and current) for a variety of mine types. These deployment methods include aircraft, surface ship, unmanned underwater vehicle, and submarine-laid mines. These mine deployment assets will be tested individually against one another with both time and inventory constraints to determine their viability in future naval conflicts. Then, they will be assessed in concert with one another using regression analysis to give warfare commanders insight into the amount of assets required to accomplish an assigned mission. The mines the assets will deploy are a sample of current and near term (within 5 years) naval mines that are in-service including the Quickstrike family of mines, and the hammerhead mine system.

12. SE Approach

This project's SE effort established the system's technical framework and provided the foundation of the project. The SE effort is based upon the February 2022 SE Guidebook (Office of the Under Secretary of Defense for Research and Engineering 2022). The SE Guidebook breaks up the SE process into sixteen (16) processes; eight (8) technical management processes and 8 technical processes (Office of the Under Secretary of Defense for Research and Engineering 2022). The eight technical processes include the top-down design processes and bottom-up realization processes that support transformation of operational needs into operational capabilities (Office of the Under Secretary of Defense for Research and Engineering 2022). The technical management processes are completed throughout the acquisition life cycle. Since the team will not be developing a physical system a modified version of the SE process will be used. This project will focus on four (4) of the technical management processes and the three (3) top-down design technical processes from the SE process outlined the SE Guidebook highlighted in Figure 4 .

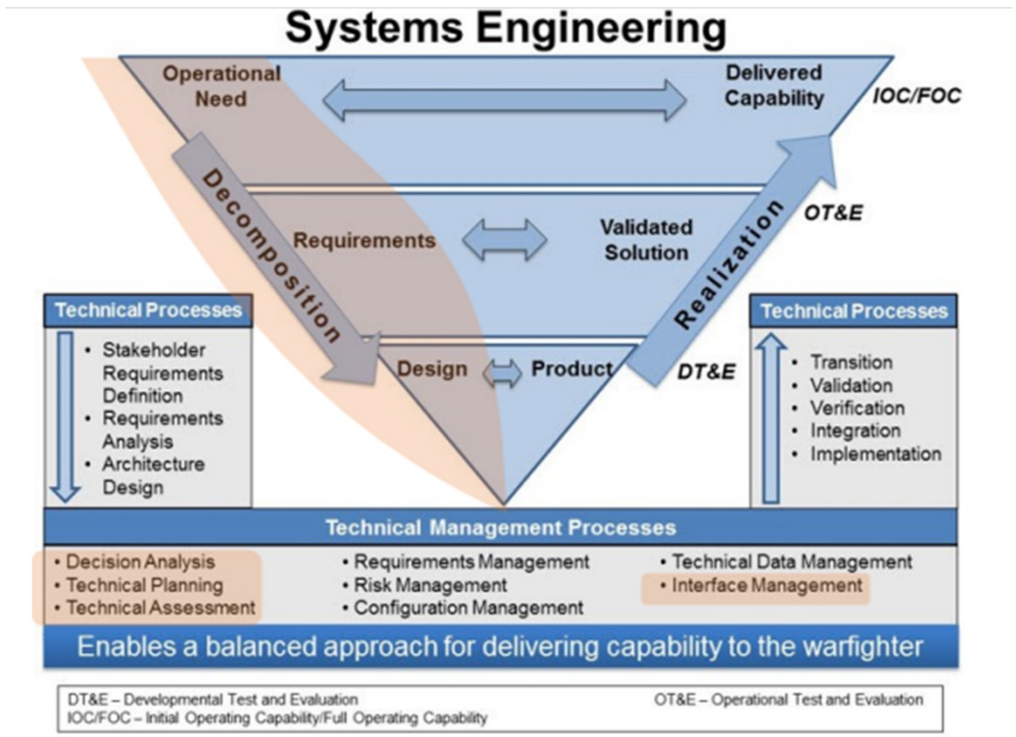

Figure 4. SE Process: Adapted from Office of the Under Secretary of Defense for Research and Engineering (2022).

As part of the Stakeholder Requirements Definition, the team interacted with the stakeholders to develop a problem statement and understand the technical requirements needed for the system. Once the problem statement and requirements were understood the team utilized a model-based SE tool called Innoslate to develop system models to further define the system and interdependencies within the system as part of the Architecture Design Process. In addition to the models the team performed trade-off analysis and decision analysis, using Microsoft Office tools and a discrete time-based simulation called ExtendSim, to determine the most effective means of mine deployment. This was done by conducting a Design of Experiments (DOE) with the help of John's Macintosh Project (JMP) to accurately determine the most critical factors for success.

Throughout the conduct of the technical SE processes the team conducted the SE management processes of technical planning and decision analysis. To support technical planning and decision analysis, the team developed an integrated master schedule (IMS) using Microsoft Office products, established measure of effectiveness (MOEs) for the system by creating time-based simulations in ExtendSim, and defined the methods for decision and trade analysis. The team used a combination of Multi Attribute Utility Theory (MAUT) and various qualitative methods to decide on functional attributes for the system. Some of the qualitative methods included Pugh, Best of Class, and Numerical Evaluation Matrices. To determine the most effective system configuration the team used ExtendSim and performed a cost-benefit analysis and risk assessment.

Although the SE approach used is a modification of the process outlined in the SE Guidebook, it is aligned with the initial Department of Defense (DOD) SE Process Model, depicted in Figure 5. In this version of the SE process the inputs include information derived from the stakeholder such as problem statement, requirements, objectives, constraints, MOEs, environments, and available technology and the process output is based on the level of development. To support this project, the process output is the effective system configuration and supporting requirements.

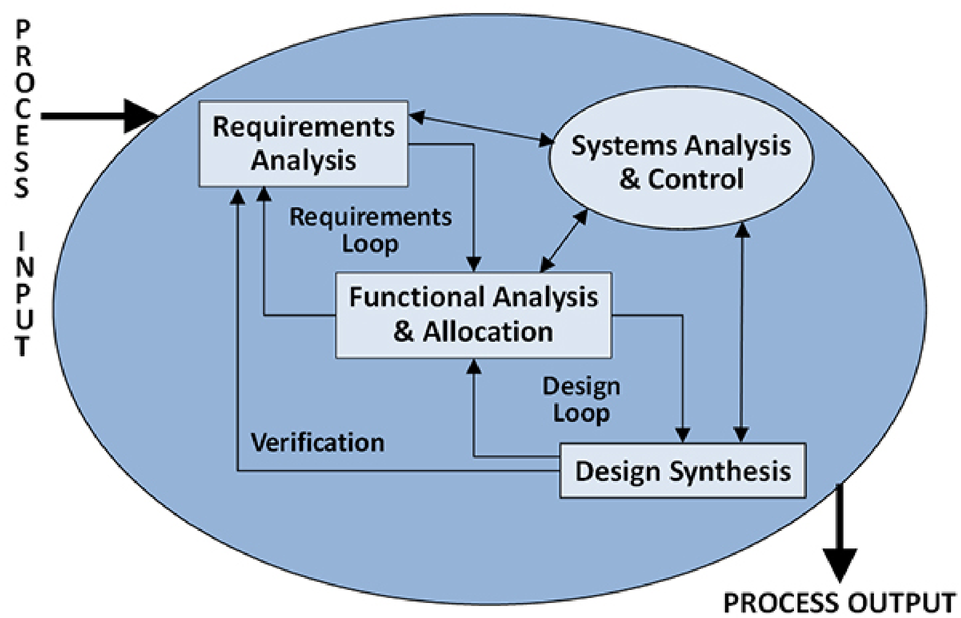

Figure 5. DOD SE Process Model. Source: Defense Acquisition University (2001).

13. Report Organization

This report is organized into five chapters, these chapters begin with the literature review conducted to define the problem space Team Trogdor was looking to explore, the research methodology employed, the definition of project scope, analysis, and findings/recommendations.

a. Chapter I

Chapter I presents the introduction defining the problem space of naval mining, refines the scope and defines the need for analysis, and the team's organization and analysis approach.

b. Chapter II

Chapter II presents the literature review including the research methodology employed by team Trogdor, the history of naval mining, the Navy's efforts to renew emphasis on fleet lethality, and a look into the ongoing efforts to develop future mining systems.

c. Chapter III

Chapter III presents the beginning of team Trogdor's analysis into the suitability of delivery assets. This chapter includes the systems architecture for mine deployment assets, the design of experiments conducted by Team Trogdor, and the description of the model in ExtendSim.

d. Chapter IV

Chapter IV presents the results from Team Trogdor's analysis. This is broken into two phases. The first phase of analysis is undertaken with ExtendSim. This software was used to describe the individual suitability of mine delivery assets. The second phase of analysis provides warfare commanders with an ability to determine how many assets are required to conduct an assigned mission.

e. Chapter V

Chapter V presents the results of analysis. This chapter includes a summary of findings as well as provides fleet recommendations for the acquisition of equipment to employ naval mines.

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II. RESEARCH METHODOLOGY

Team Trogdor's literature review strategy consisted of readings that can be ascribed to one of three categories. The historical/contextual category allowed the team to gain a historical reference of how U.S. doctrine supported mining operations in the past. The second category pertained to modeling data and current systems. These readings set out to inform the team on both current system capabilities and how they can be modeled to provide accurate measurements of mining systems employment. The third category for research was future systems. This gave the team an idea of future capabilities being developed to augment mine employment in the future.

The project's initial step was to cultivate an understanding of the warfare area. This included an analysis of current and past mine employment, current systems, and future systems in development. This included research into the MIW warfare area including mine countermeasures. In conducting this analysis, the team investigated historical accounts of the use of mine systems in their historical contexts, periodicals provided by the United States Naval Institute which included expert analysis into the current performance gaps into the U.S. Navy's current gaps in offensive mine employment capabilities, and published articles by reputable news outlets, military journals, and other expert analyses. The team also read current operational doctrine in the form of Joint Publications published by the Chairman of the Joint Chiefs of Staff (CJCS) as well as current Navy-specific doctrine which came in the form of naval tactics techniques and procedures (NTTP) published by SMWDC.

A. HISTORY OF U.S. NAVAL MINE WARFARE

American use of mine warfare (MIW) traces its lineage back to the founding of the Nation. America's invention and first use of naval mines occurred during the American Revolutionary War in 1777 (Naval History and Heritage Command 2021). David Bushnell, a student at Yale University, invented a wooden barrel filled with gunpowder that was attached to a floatation device shown in Figure 6. A hammer from a service pistol was attached to the barrel and would ignite the gunpowder upon contact with an enemy ship.

The mines were delivered to their target by sea current. The undercurrent would push the keg towards unwary British ships docked ashore or anchored offshore. These types of rudimentary naval mines were used twice during the Revolutionary War (Rogoway 2020).

Figure 6. The Bushnell Mine. Source: Rogoway (2020)

The first use of naval mines was against a sixth-rate[1] British frigate named HMS Cerberus which was at anchor in Black Point Bay off the coast of New London, Connecticut (Royal Museums Greenwich n.d.). The mines depicted were released by Bushnell from a fishing trawler towards the unsuspecting Cerberus. An unseen schooner[2] anchored between the fishing trawler and the Cerberus intercepted one of the mines and fished it out of the water. The mine detonated, killing three of the Sailors onboard and sinking the schooner. The Cerberus remained unharmed but quickly left anchor and set sail for Connecticut to warn Royal Navy superiors about this new weapon (Rogoway 2020). This example illustrates that naval mines do not have to make kinetic impact with their target to impact enemy movement and decision-making. Four months later in January 1778, the second use of these mines occurred. Bushnell released an additional twenty newly

[1] The term "Sixth Rate" refers to the armament being carried on and the subsequent size of British naval ships. The first four ratings are assigned to "ships of the line." These ships were designed to deliver and receive heavy enemy fire from the broadsides. The fifth and sixth-rate were classified as Frigates. These ships were smaller, more maneuverable, and were designed with 40–44 guns and 20–28 guns respectively. These ships were assigned escort, scouting, and patrol duties in support of larger combatants.

[2] A schooner is a category of British naval ships. Whereas first through sixth-rate ships were ships designed for warfare and armed warship escort duties, schooners were primarily used for fishing and running supplies between the warships.

modified versions of these mines on the Delaware River, destroying a small boat and causing British ships to spend a full day shooting anything (not a ship) that floated on the water. This became known as the "Battle of the Kegs" depicted in Figure 7 (Rogoway 2020). The use of naval mines during the Battle of the Kegs gave early insight into the psychological effects of naval mines on adversary navies.

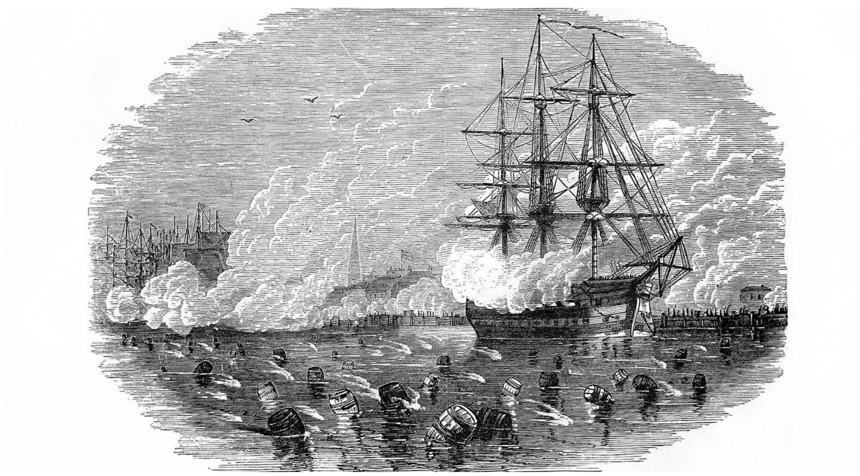


Figure 7. The Battle of the Kegs. Source: Rogoway (2020)

During the Civil War, the Confederate Navy was considered to be inferior to the Union Navy in both number of ships and their capabilities. To gain an advantage, the Confederates turned their attention towards MIW, lining their coastline with a variety of mine designs (Melia 1991). During the Battle of Mobile Bay, depicted in Figure 8, Confederate mines sank 27 Union vessels. Union Admiral David Farragut would eventually isolate Fort Morgan, the last of the Confederate forts defending Mobile Bay, Alabama (American Wars US 2017). It was during the Battle of Mobile Bay in 1864 that Admiral Farragut uttered the famous phrase "Damn the torpedoes, full speed ahead!" At that time, the term "torpedo" was used to describe the naval mines (not actual torpedoes) used to fortify Fort Morgan against the incoming Union Navy (Klein 2018). The use of naval mines during the Civil War shows how mines placed ahead of an invasion attempt can have disproportionate effects against the enemy, both psychological and kinetic.

Figure 8. The Battle of Mobile Bay Source: Klein (2018)

When the United States entered World War One (WWI) in defense of its allies in 1917, merchant ships transporting troops and supplies throughout Europe were being attacked by German U-Boats (submarines) with devastating effects (Conrad 2018). In February 1917, unrestricted submarine warfare against merchant shipping was declared by Germany. During the next six months, losses in Allied cargo averaged a weight of approximately 600,000 tons a month (American Battle Monuments Commission 2018). In early July of 1917, the U.S. and its allies adopted a convoy system, cutting the losses in cargo to 450,000 tons a month which, if allowed to persist, would have still resulted in a failure of the Allied cause (Naval History and Heritage Command 2020). After almost a calendar year of optimization and deliberations, in March of 1918, Allied forces began laying a barrage of Mark VI mines outfitted with floatation devices to detonate at various depths with the intent of detonating on contact with submerged German U-Boats shown in Figure 9. The United States would lay a total of 72,000 mines up until the armistice was signed, ending the hostilities of WWI with Germany (Conrad 2018). From the beginning of the Northern Barrage to the end, naval mines would sink or damage as many as 21 U-Boats and deterred continued hostilities against Allied shipping (American Battle Monuments Commission 2018).

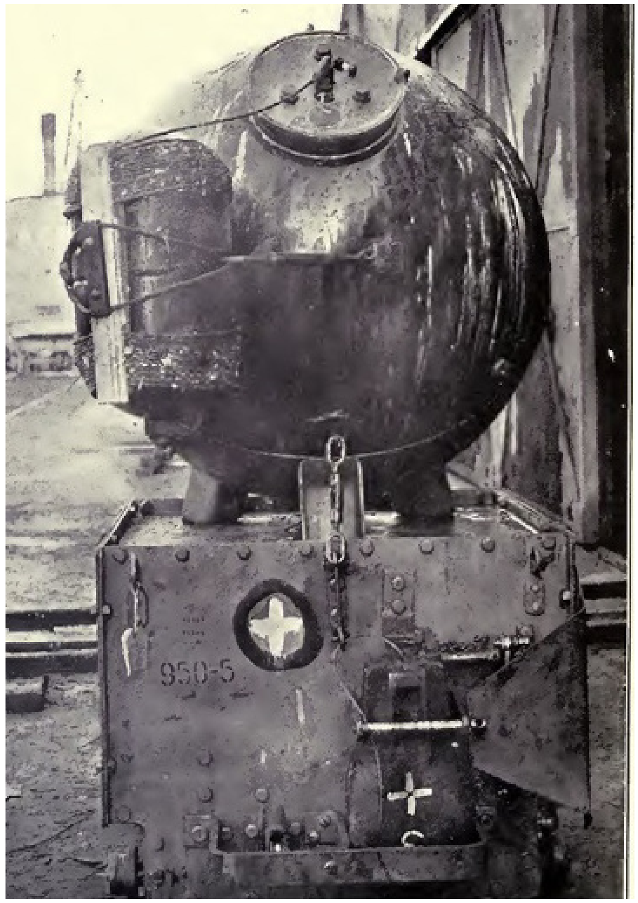


Figure 9. The Mark VI Mine. Source: Conrad (2018)

In the aftermath of WWI, the American Navy undertook the effort of clearing the mines laid in the Northern Barrage. Under the supervision of Rear Admiral Strauss, sweeping operations were conducted with two ships towing a cable-cutting device that would sever the mine from its cable and cause it to float to the surface (Melia 1991). The "A" formation equipped with serrated cable-cutting devices between them is depicted in Figure 10. This was a time and labor-intensive effort which involved 421 naval vessels, and 15,600 Sailors, and lasted from April 1, 1919, through November 20, 1919, with crews working 17- to 18-hour days (Melia 1991). Despite the large scale of this minesweeping effort, it only dispensed with 40 percent of the American mines making up the Northern Barrage. The rest were assumed by higher officials to have exploded during the war. This was a folly assumption, with many of the mines used in the Northern Barrage washing ashore many years later (Melia 1991). The use of mines in WWI provides a twofold lesson on the use of naval mines. The first, the larger the geographic area required to cover, the more mines that are required. The second is that recovery and disposal is an important planning consideration when laying a minefield. Tens of thousands of mines were laid during WWI, only a fraction of which were ever recovered.

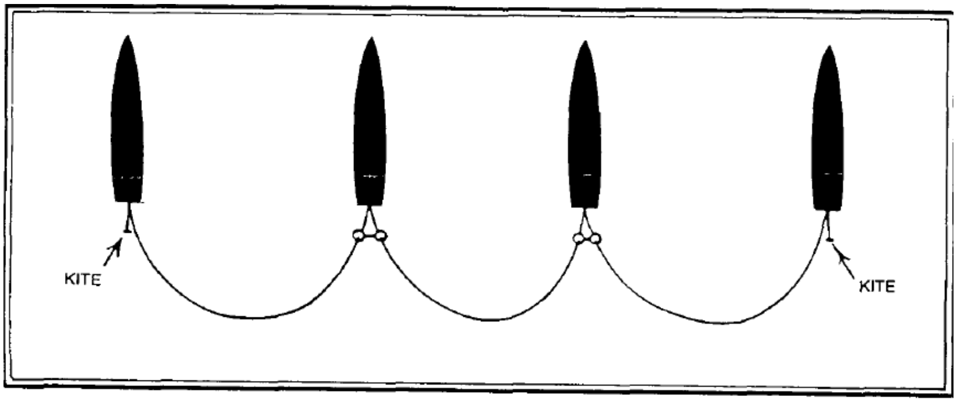


Figure 10. Mine Clearing Formation. Source: Melia (1991)

During WWII mines were used to attrite and defeat the empire of Japan. During OPERATION STARVATION in 1945, U.S. aircraft planted more than 20,000 influence mines with a combination of actuation methods in a wide area throughout the Pacific with the B-29 Stratofortress and other aircraft depicted in Figure 11. The mines would have devastating effects on both the Japanese fleet and merchant shipping supporting their war effort (Vogel 1947). Naval mines resulted in the sinking of 650 Japanese ships and the disruption of all maritime shipping in the area. Commander Seburo Tadennuma of the Imperial Japanese Navy described the mines as "one of the main causes of [their] defeat" (Lott 1959). After WWII, the combatants of the war did not endeavor to repeat the actions of the war. As a result, all nations involved substantively downsized their military. OPERATION MAGIC CARPET (October 1945 – September 1946) repatriated over eight million military servicemembers overseas using 370 Navy ships. This massive drawdown also resulted in MIW falling into the background of America's strategic consciousness (English 2019). WWII illustrates the relevance of using strategically placed mines to effect political outcomes without loss of life. The mines in themselves can be used as a deterrent both for merchant traffic and in shaping the battlespace.

Figure 11. B-29 Dropping Naval Mines Over Japan. Source: Baccaglioni (2017)

Following the military downsizing following WWII, the Korean War sparked a renewed focus on naval MIW. The Korean Navy was relatively small compared to that of the U.S. Navy's occupying force. The Korean Navy had 45 vessels compared to the 250 vessels making up the US's occupying force (Roblin 2020). In keeping with the ideas of asymmetric warfare,[3] the Korean Navy employed 3000 mines in the waters surrounding North Korea (Sexton 2016). The United States lost five ships during the Korean War, all five of which struck a Korean mine. Figure 12 depicts a South Korean minesweeper striking a North Korean mine during mine clearing operations. Seventy percent of all naval

[3] Asymmetric warfare is when a numerically inferior force attempts to diminish, demoralize, or attrite the numerically superior force without direct engagement. This is seen on the seas with MIW in Korea, in the Middle East with the Iranian small boat threat and in the ground wars in Iraq and Afghanistan with the use of improvised explosive devices (IEDs)

ship casualties[4] were directly attributed to naval mines (Preston 2014). The Korean War also represented the first time the United States entered an international war wherein the objective was not a total victory, which constrained their use of highly destructive munitions (mines). The Korean War in this case provides a relevant historic example of how mines can be used asymmetrically (that a numerically inferior actor can have more destructive effects against a numerically superior adversary).

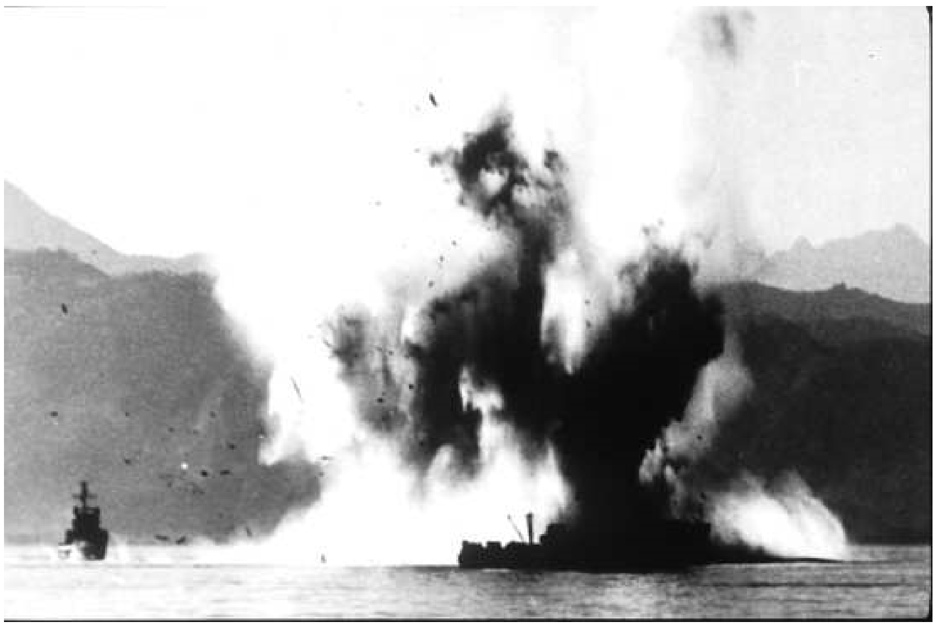


Figure 12. Minesweeper Struck by North Korean Mine. Source: Roblin (2020)

A year after the Korean War ended, the Vietnam War began. U.S. involvement in the region sought to resist a communist takeover in South Vietnam by the North Vietnamese (History.com Editors 2023). Throughout the Vietnam War, the U.S. provided support to the South Vietnamese and their leader Ngo Dinh Diem. Policymakers in the U.S. were working under the "domino theory" (History.com 2022). The prevailing opinion was if one country in the South Pacific fell to a communist regime, the rest would soon follow.

[4] Casualties describes both personnel and material degradations to equipment. Damage to a ship's propeller resulting in her inability to maneuver through the water is an example of a casualty.

"By 1962, the U.S. military presence in South Vietnam reached … 9,000 troops, compared with fewer than 800 in the 1950s," and from 1965 to 1968, the Rolling Thunder bombing campaign took place (History.com Editors 2023). During the three-year campaign, U.S. carrier air wings planted thousands of mines in the intercoastal and inland supply routes, shipping routes around the "panhandle," and key roads of North Vietnam. Four years later in 1972 and in early 1973, USS CORAL SEA (CVA 43) launched thirty-six 1,000-pound Mark 52 mines in the waters approaching Haiphong harbor, reseeded by thousands more in the months following. The mining effort sought to keep twenty-seven Soviet merchant ships from leaving Vietnam for resupply. Mining operations shortened the Easter Offensive against South Vietnamese and U.S. Forces in mid-to-late 1972 like the Soviet freighter Mtsensk shown in Figure 13 (Silva 2020).

Figure 13. Soviet Freighter Mtsensk in Haiphong Harbor. Source: Silva (2020)

In January the following year, the U.S. and the Vietnamese (North and South) signed the Paris Peace Accords which ended the Vietnam War and stipulated that the U.S. neutralize the mines it had dropped in and around North Vietnam. For the next six months, U.S. forces swept the waters in OPERATION END SWEEP. The effort involved "10 ocean minesweepers, 9 amphibious ships, 6 fleet tugs, 3 salvage ships, 19 destroyers, [and 31 helicopters]" (Marolda 2020). Figure 14 is a CH-53D Sea Stallion conducting mine sweeping operations in North Vietnam. The effort was halted briefly due to Hanoi's failure to act according to the Paris Peace Accords but on July 18, 1973, Rear Admiral Brian McCauley, the commander of Mine Countermeasures Task Force 78 conducting OPERATION END SWEEP led his forces out of the area, ending the operation (Marolda 2020). Even with the substantially decreased number of mines deployed during the Vietnam War as opposed to WWI, countermining and minesweeping operations is a laborious and dangerous exercise, which provides operational planners insight into the planning considerations for not only the conflict itself but also its aftermath.

Figure 14. CH-53D Sea Stallion Sweeping for Mines. Adapted from Silva (2020)

U.S. conflict with communist governments continued during the Cold War. Despite the historic success of MIW in the past, the United States shifted its focus toward high-end ASCM and ASW threats (National Academy of Sciences 2001). This shift in focus resulted in a decreased emphasis on mining and counter-mining operations despite fourteen out of the sixteen ships that were sunk from WWII to the Cold War were a result of mines (English 2019). During the Cold War, the U.S. Navy relied primarily on North Atlantic Treaty Organization (NATO) allies to conduct counter-mine operations. Despite this decrease in training and funding, the U.S. did develop the Mark 60 CAPTOR mine (shown in Figure 15), a 2,000-pound mine capable of employing its own Mark 46 torpedo upon detection of threat submarines (English 2019).

Figure 15. CAPTOR Mine onboard B-52 Stratofortress. Source: Kirill (2020)

In July 1987, leading up to U.S. involvement in the First Gulf War, the Navy began escorting Kuwaiti tankers during OPERATION EARNEST WILL. OPERATION EARNEST WILL was in direct response to Iran shutting down the Strait of Hormuz[5] (Naval History and Heritage Command 2015). During this operation, a mine struck the supertanker Bridgerton followed by three more supertankers in the first month of the operation (Naval History and Heritage Command 2015). This resulted in the U.S. conducting both escort duties and counter-mining operations in the region. On 21 September of that same year, Iranian ship IRAN AJR was tracked leaving Iranian territorial waters. On 22 September, IRAN AJR was boarded and captured (shown in Figure 16) during their attempt to conduct mining operations in the Persian Gulf (Peniston 1988).

[5] The Straits of Hormuz is a nautical chokepoint between the countries of Iran and the United Arab Emirates. Iran shutting down the Strait was not in accordance with international law which stipulates that international straits between two unincorporated bodies of water are navigable.

Figure 16. U.S. Sailors Board Iran Ajr. Source: Peniston (1987)

On April 14, 1988, lookouts onboard USS SAMUEL B. ROBERTS (FFG 58) sighted three mines 1,000 yards from the ship. Twenty minutes later, she[6] struck a submerged mine, rendering her incapable of further missions, and returned to the U.S. for repair (Perkins 1989). The U.S. responded to the loss of FFG 58 with OPERATION PRAYING MANTIS destroying two oil platforms, six Iranian speedboats, and three Iranian warships like the Iranian frigate SAHAND which is depicted in Figure 17 being struck by American 1000-pound bombs and harpoon missiles. This display of U.S. commitment to stability in the region encouraged cooperation during OPERATION DESERT STORM/SHIELD which occurred from August 2, 1990, to February 28, 1991, and resulted in Coalition victory (Perkins 1989).

[6] "She" is the pronoun used to describe a ship. This traces its origins to Latin language wherein "Navis" (the Latin word for ship) is feminine. It additionally traces its origin to British naval tradition, from which the U.S. Navy takes many of its traditions from the term "she" referring to a ship, to rank structure, to celebrations, and many more (Imperial War Museums 2023).

Figure 17. Iranian Frigate SAHAND (F 74) Struck by U.S. A-6s. Source: Peniston (1988)

Twelve years later in 2003, during OPERATION IRAQI/ENDURING FREEDOM, Mine Countermeasure Squadron (MCMRON) 3 began counter-mining operations 12 hours after the start of combat operations ashore. The U.S. presence in the Persian Gulf precluded Iraqi ships from laying mines in the region (Ryan 2003). The presence of mine countermeasure (MCM) assets in the region to preclude adversary use of mines is a prime example of active MCM. U.S. and Coalition forces were able to interdict "several uniquely configured Iraqi minelayers" and were able to interdict more than 100 mines prior to them being placed in the water due to satellite imagery and operational intelligence. The counter-mining operations were a joint effort with the unmanned underwater vehicle (UUV) the Remus, helicopters, dolphins,[7] explosive ordnance disposal (EOD) teams, and Avenger-class minesweepers. This effort allowed the safe ingress of "six carrier battle groups (CVBGs), four amphibious ready groups (ARGs), [numerous] support ships, and [approximately] 60,000 active-duty Sailors and Marines and 13,000 reservists (Ryan 2003).

[7] Navy dolphins are trained to use their biological sonar to detect mines (Savitz 2022).

B. A RENEWED FOCUS ON FLEET LETHALITY

The United States Navy has enjoyed a relative lack of competition on the high seas since and has not been engaged in a large-scale naval battle since WWII. The mission of the U.S. Navy; to "protect America at sea alongside [its] allies and partners, defend freedom, preserve economic prosperity, and keep the seas open and free" will likely be contested in the future (U.S. Navy Office of Information 2023). In an endeavor to prepare the fleet and its Sailors for combat operations at sea, a new emphasis has been placed on fleet lethality. This has manifested itself through the establishment of the surface and mine warfighting development center (SMWDC) and the warfare tactics instructor (WTI) program in 2015 (LaGrone and Eckstein 2016). The SMWDC and the WTI program are modeled after the naval advanced warfighting development center (NAWDC) (better known as TOPGUN) to provide highly specialized and technical training junior officers specializing in the physical domains of naval warfare; surface warfare (SUW) anti-submarine warfare (ASW), amphibious warfare (AMW), and integrated air and missile defense (IAMD) (Eckstein 2018). A year after the program was established, USS MASON and USS NITZE were attacked during OPERATION BAM by Houthi rebels in 2016. This forced to U.S. Navy to realize that its Sailors were not prepared for the high-end fight and would have to quickly adapt to threats on the high seas (Wade and Baker 2017). Further recognizing a gap in warfighting readiness, the navy established the MIW WTI program to augment the original four types of instructors. The first class of five MIW WTIs graduated in 2019 with the majority of their training taking place in Belgium for a total of thirty weeks (the longest of the warfare area curriculums) (U.S. Navy Press Office 2018) (DVIDS 2020). SMWDC along with the WTIs conduct pre-deployment tactical training known as surface warfare advanced tactical training (SWATT) exercises.

Despite this shift in mindset, readying the U.S. Navy for combat operations is an ongoing effort. During a wargaming exercise in fall of 2020, the Navy used current doctrine against a simulated current Russia and China. With the then current doctrine employed during the wargame, the U.S. will not meet its military objectives and will have to exercise creativity to remain ahead of adversary tactical and operational planners (Pickrell 2021). In order to deter future Chinese and Russian aggression, the Department of Defense (DOD) came up with the "expanded maneuver" doctrine. This doctrine is characterized as "understanding how [the enemy] can operate in all domains and how to stop them while protecting DOD and coalition forces" (Vergun 2021). The four "functional battle areas" of this doctrine are contested logistics, joint fires, joint all-domain command and control (C2), and information advantage (Vergun 2021). MIW, specifically mining operations can provide U.S. capabilities to the contested logistics and joint fires "functional battle areas."

Chapter II Section A.1 captures the advent of naval mine warfare in the U.S. and captures examples of its use throughout history. "A Renewed Focus on Fleet Lethality" provided an introduction to the evolving future threat environment, the steps the U.S. Navy has taken to gain an advantage in that environment, and where mines and mine warfare may prove critical in the employment of future concepts of operations. The following sections of this chapter provide specific research questions and outlines the problem that will be answered within this report including the engineering process that will be employed to answer them.

C. MODELING DATA AND CURRENT SYSTEMS

The need for this research has become more apparent as the global superpowers have reached new levels of global political tensions in recent years. (Rowden, Gumataotao and Fanta 2015) highlighted CNO Admiral Jonathan Greenert's three tenets. Of his three tenets "Warfighting First" is at the top. It brings into context that all this analysis being done is really in support of one objective, warfighting. All other goals are in support of this mission. It also discusses several scenarios with a focus on lethality. Team Trogdor will identify lethality measurements of effectiveness (MoE) for our model.

In a previous capstone report on offensive mining operations (Deken, et al. 2021) insights were provided into using modeling and simulation methods to illustrate the effectiveness of offensive mining operations and applies a modified Vee SE approach to system development. Building off this capstone's findings, the modified Vee system engineering approach will continue to be used for further modeling and simulation efforts.

JP-3 (Joint Chiefs of Staff 2020) was used to help define the military objectives as codified in U.S. military doctrine. This article focuses on a militaries' campaign objectives and the necessity to have clearly defined goals. These objectives are split up into tasks for each different component to work towards. This article was helpful in choosing the objectives of the mine laying campaign worked in conjunction with the Forces Capabilities Handbook by the Naval War College, which discussed the purpose and capabilities of all the different U.S. armed forces. Together, these documents allowed us to further identify the problem statement and select the appropriate decisions the blue actors will take within the scenario.

By using Adm. Jonathan Greenert's tenet of lethality to establish our MoEs, the 2021 capstone's work with the modified Vee SE approach, and the Joint Chiefs of Staffs outline for objective measures, Team Trogdor has the foundational components to build a functional model and simulation strategy.

D. FUTURE SYSTEMS

As new technologies are constantly being developed or innovated, mine technologies as well as delivery methods have also seen rapid growth. The use of autonomous unmanned vehicles in the Air, Surface, and Submarine environments, has created more potential for mines to be deployed without the added risks of sending a manned vehicle. Jan Tegler explains how the countermining fleet is diminishing in the current environment with only 8 of 14 Avenger anti-mining ships and 30 (or fewer) of the 44 MH-53E Sea Dragon helicopters still in operation for anti-mining operations (Tegler 2023). These ships are scheduled for release but the failure of the Littoral Combat Ship (LCS) to take as a fully operational fleet mine countermeasure asset has caused production to stagnate and MCM assets to continue diminishing as a result. Offensive mining operations are currently being transferred from surface fleet to submarine force (SUBFOR). Programs are in place for using unmanned underwater delivery vehicles for delivery of mines.

On top of these developments, the mines themselves have documents of future products. (SAES 2023) MINEA is a next generation smart mine that combines sensors, magnetic, electrical, acoustic, pressure and seismic influences, combined with artificial intelligence to determine the profile of a potential target and only detonate based on a successful match. They can be deployed from any type of vessel including through torpedo tubes. It also allows for automatic collection of mines when operations conclude, and they can be reconfigured after deployment using an acoustic link. The need for such smart mines has been discussed in (Uppal 2019). The main topic is the current state of the naval mining world and the desire to upgrade into a mine with better sensors, capabilities, and batteries as part of the hammerhead mine program. These mines potentially could stay active for months at a time, much longer than previous smart mines. They could maneuver to meet the growing needs of the Navy.

III. ANALYSIS APPROACH

This chapter presents the model and assessment strategy used in this report. First, operational considerations that guide model development are presented. Second, a description of the model and the associated system representations is presented. The model was developed in an interactive process through the use of functional models and discussions with stakeholders, as described in Chapter II. The systems architecture was developed in an interactive process through use of the functional analysis models, development of the simulation tool, and discussions with stakeholders. The models in Section II.J display the final result of the iterative process.

A. OPERATIONAL AND SYSTEM CONSIDERATIONS

Mission requirements and commanders' intent during a military operation are variable depending on the acceptable level of risk (ALR), rules of engagement (ROE), and current geopolitical disposition. Time, inventory, and asset availability are the primary constraints warfare commanders face, and those are the three the team will explore in this analysis.

1. Fixed Time

The team will fix the time to reflect the real-world constraint of conducting mining operations with a fixed deadline. In this model, this will show how assets perform in a finite period whether that be a week or a month. Due to computing power and the amount of different runs the team needs to conduct a maximum runtime will be set for the assets to deploy the required number of mines. A separate study will be conducted allowing the assets to deploy as many mines as possible in a separate timeframe to aid in the analysis of these systems.

2. Fixed Inventory

The munitions inventory constraint facing the U.S. military in 2023 is a problem-binding reality (Grady 2023). In this experiment, this will show, given a set inventory, how quickly each asset is able to deliver the required payload for a given mission and R2B.

3. Individual Asset Suitability

A low P_d is the goal for any covert military operation. Assets are assigned a P_d based on interaction with stakeholders regarding the design and operational characteristics of each system. In this analysis, the intent is to deploy assets until a deploying asset is detected and has to leave the AOR.

4. Multi-Asset Configurations

Following the previous three assessments, the team will determine the overall suitability of each asset with the constraints of time, inventory, and their P_d. These will be used to inform each asset's overall effectiveness. At which time, the analysis will make assessments to use for operational planning. This will include a regression analysis to assign a mission and illustrate the number of individual assets required to accomplish a mission to a defined level of effectiveness. This will allow decision makers to determine the number of assets required to be outfitted with naval mines to achieve fleet objectives.

B. MODEL DESCRIPTION

1. Model Setup And Assumptions

The model is a stochastic representation of our mine delivery system. The model is built using ExtendSim and supports four different types of delivery assets/asset configurations. The model represents the Orca XLUUV, a Virginia class conventional submarine, a Freedom class littoral combat ship (LCS), and the B-52. The simulation creates a representation of each asset's given attributes fed by the inboard database. The basic assumptions for transit time, cargo capacity, travel times, P_d, and intended mission size for each asset are outlined in Table 1.

Table 1. Baseline Initialization Assumptions

Delivery Asset	**Cargo Capacity (#of Mines)**	**Deployment Time (hrs.)**	**Inter-mine Time (hrs.)**	**In-Port Time (hrs.)**	**Transit Time (hrs.)**	**P_d**	**Mine Target**
Orca	12	0.1	0.16	12	336	0.01%	400
Submarine	18	0.05	0.1	48	432	0.05%	400
LCS	166	0.33	0.33	96	125	1%	400
B-52	101	0.01	0.01	24	21	10%	400

Table 1 outlines the underlying assumptions of the model including the type of asset deploying mines, the cargo capacity for each respective delivery platform, the deployment time, inter-mine time, in-port time, transit time, P_d, and mine target. The following subsections describe the implementation of each attribute or system in the ExtendSim model.

- Delivery Asset

The delivery asset illustrates the mine deployment asset that is going through the model in a given run. The MK62, MK63, and MK65 delivery assets each represent a B-52 bomber aircraft outfitted exclusively outfitted with that type of mine.

- Cargo Capacity

The cargo capacity variable dictates the number of naval mines (Quickstrike mines in the case of the B-52 bombers and the hammerhead mine for the LCS, Submarine, and Orca XLUUV) they can carry during one sortie.

- Deployment Time

Deployment time represents the amount of time it takes (or is theorized to take) for a deploying asset to deploy the mines including preparation of equipment and personnel, the mine deployment, and the return of the delivery asset to readiness condition.

- Inter-mine Time

Inter-mine time is the variable that represents the amount of time it takes for a delivery asset to transit from one site for mine deployment to another to attain assigned mine coverage for a given area.

- Port Time

At the end of the run (or individual mission) the port time represents the amount of time, in hours, that the platform will stay in port. This encompasses the amount of time the delivery asset will take to onload new munitions (during daylight hours, given current safety requirements), take on fuel, conduct routine maintenance not accomplishable underway, connect and subsequently disconnect pier support services (potable water, shore power, and shore sewage connections) proceed out for the next mission as required by the respective asset.

- Transit Time

Transit time represents the amount of time (given the assumed best economic speed of the platform) to transit from their respective bases to the area in which they are to deploy their first mine.

- P_d

P_d represents the probability that an asset will be detected and their activity recognized by a threat platform during their mission. This term's use in this analysis differs from the ubiquitous use of the term. This most commonly refers to whether or not an asset has simply been seen operating in the area. Operating under the presupposition that minelaying in this analysis is a peacetime endeavor, this term refers to the probability that the unit has been physically detected in the vicinity and is conducting minelaying operations. This probability, if realized during each mine deployment, results in mission failure of the deploying asset and a subsequent R2B. An asset is considered detected if P_d reaches 50 percent.

- Mine target

Mine target represents the intended number of mines to deploy through the totality of an assigned mission (multiple runs). This value will vary depending on the commander's intent for the mission as well as represents the real-world constraint of the U.S. Navy's current operational environment.

2. Model Behavior

The simulation creates one or more of the platforms for deployment. These are then fed into the simulation, as depicted in Figure 18. The depiction of the model shown in Figure 18 was produced by Innoslate. It is not intended to be fully accurate from a model-based systems engineering standpoint. Rather, it simply displays the sequence of the model for the reader to understand the otherwise illustratively cumbersome ExtendSim model. The first step each platform must take is to travel to the battlespace. The assumption of travel time is used as the mean for a random distribution with 10 percent of the mean used for the standard deviation for travel time. This same formula is used at all blocks with randomized values based on the relevant assumption for that block.

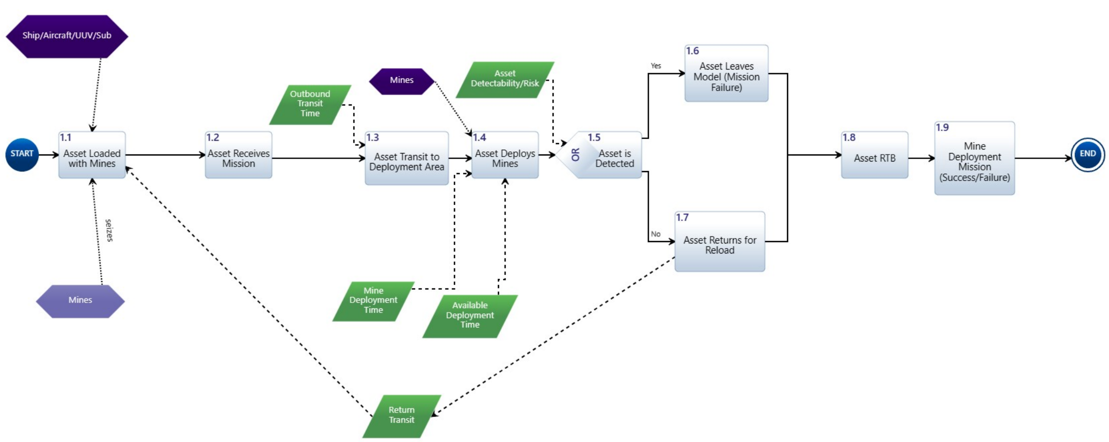


Figure 18. Activity Diagram of Mining Simulation

Upon arriving at the battlefield, the LCS and B-52s are only permitted to start mining operations at night so they are placed in a queue waiting for nightfall defined as the hours between 1900 and 0600. The other platforms are able to operate 24/7 and are allowed to begin deploying mines immediately. Once allowed into the battlespace, each platform will begin distributing mines. The asset will go back through the model until the target number of mines have been delivered and they exit the model successfully. Upon detection all platforms of the same class are marked as detected and will take the first opportunity to exit the model indicating mission failure.

After the platform has deployed all of its mines it will then travel back to its home port and any assets which were detected will exit the simulation at this point. All undetected platforms will then wait for their port time before starting another run and returning to the battlespace.

The platforms will continue to loop through the battlespace until they are either detected or once they have fully deployed their required number of mines. Every time they successfully complete a mission the run counter will increment on the item and if a platform is able to deploy all their mines, they will be permitted to exit with the success checkbox checked.

IV. ANALYSIS RESULTS AND CONCLUSIONS

Team Trogdor ran the discrete event model illustrated by Figure 18 in Chapter III to gather the relevant data. The model was developed in a discrete event modelling software called ExtendSim. This was done to assess the performance of assets with the attributes outlined in Table 1. These assets utilized variability in transit times, P_d, and deployment times to reflect the Navy's dynamic operating environment. To investigate the combinations of asset quantities and individual asset probability of detection that have the largest impact on operational effectiveness, a formal experimental design strategy was used to define the experimental configurations used in the model. A nearly orthogonal and nearly balanced design, developed by Vieira (2013) was generated for eight total variables, the quantity of each of the four assets and the probability of detection for each asset. The maximum and minimum values used for each variable have a standard deviation of 10 percent applied to them (with the exception of mine inventory onboard each platform and the mission-assigned 400 mines). The objective of the assets in the analysis were to deliver a payload of 400 mines into their respective operating areas. The experimental design comprised 512 different system configurations. To capture the variability within the model each configuration was replicated 30 times, for a total of 15,360 total simulation runs (Viera 2013). Team Trodgor's data derived from the simulation runs and subsequent conclusions are defined in this chapter.

A. ANALYSIS RESULTS

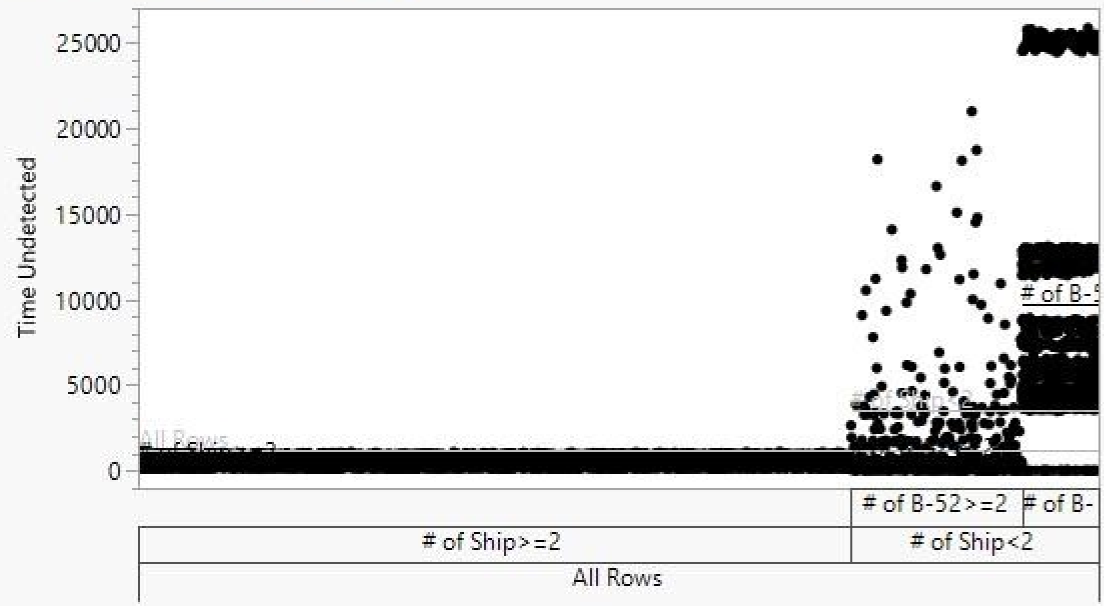
The mission assigned to all assets was to deploy 400 mines in support of fleet objectives. With 512 system configurations, replicated 30 times, Figure 19 and Figure 20 indicate the results for time undetected and individual detections which are directly attributed to mission success or mission failure.

The data analysis and figures displayed in this report are produced in the statistical software program JMP to illustrate and analyze the large quantities of statistical data derived from the ExtendSim model. Additional figures illustrating the performance for all four assets is available in the appendix. The NPS SE department maintains a repository of all thesis models and data. The full dataset is available upon request to the SE department.

Figure 19, the Time Undetected Partition graph, shows the relationship between all the simulated variables and the time undetected result and will create a partition based on the variable of highest significance in the linear regression value of R-Squared. As additional partitions are added, the stronger the correlation between the R-Squared value and the variables. Figure 19 shows the quantity of ships and the amount of time it takes to accomplish the mission. With fewer than two ships, the amount of time it takes to deploy 400 naval mines is just longer than 3488 hours. When two or more ships are included, the average plummets from 3488 hours down to approximately 457 hours to accomplish the mission. In the instance where fewer than two ships are included, the number of B-52s has the next highest correlation. When more than two B-52s are included, the time to accomplish the mission is still relatively low with 660 hours, but with a larger standard deviation. When both the number of ships and the number B-52s are less than two, the average total time to accomplish the mission became 9765 hours with a standard deviation of 6600 hours.

Figure 20, the B-52 Detection Partition graph, shows the relationship between the number of B-52s and the number of detections. There is a high probability of detection with fewer than four B-52s; however, there is a low probability of detection with four or more B-52s. Therefore, although B-52s may complete the mission quickly they bring with them a higher Pd and, consequently, mission failure. This is illustrated in Figure 20 by the appearance of continuity of the plotted data points next to one, two, and three B-52s.

Partition for Time Undetected



Split | Prune

RSquare	RASE	N	Number of Splits	AICc
0.622	1963.3081	15360	2	276529

All Rows

		Logworth	Difference
Count	15360		
Mean	1239.1278	633.02943	3030.22
Std Dev	3192.108		

# of Ship>=2

Count	11400
Mean	457.899
Std Dev	150.70063

# of Ship<2

		Logworth	Difference
Count	3960		
Mean	3488.1199	676.57073	9105.75
Std Dev	5713.8842		

# of B-52>=2

Count	2730
Mean	659.81933
Std Dev	1416.141

# of B-52<2

Count	1230
Mean	9765.5674
Std Dev	6596.2587

Figure 19. Time Undetected Partition

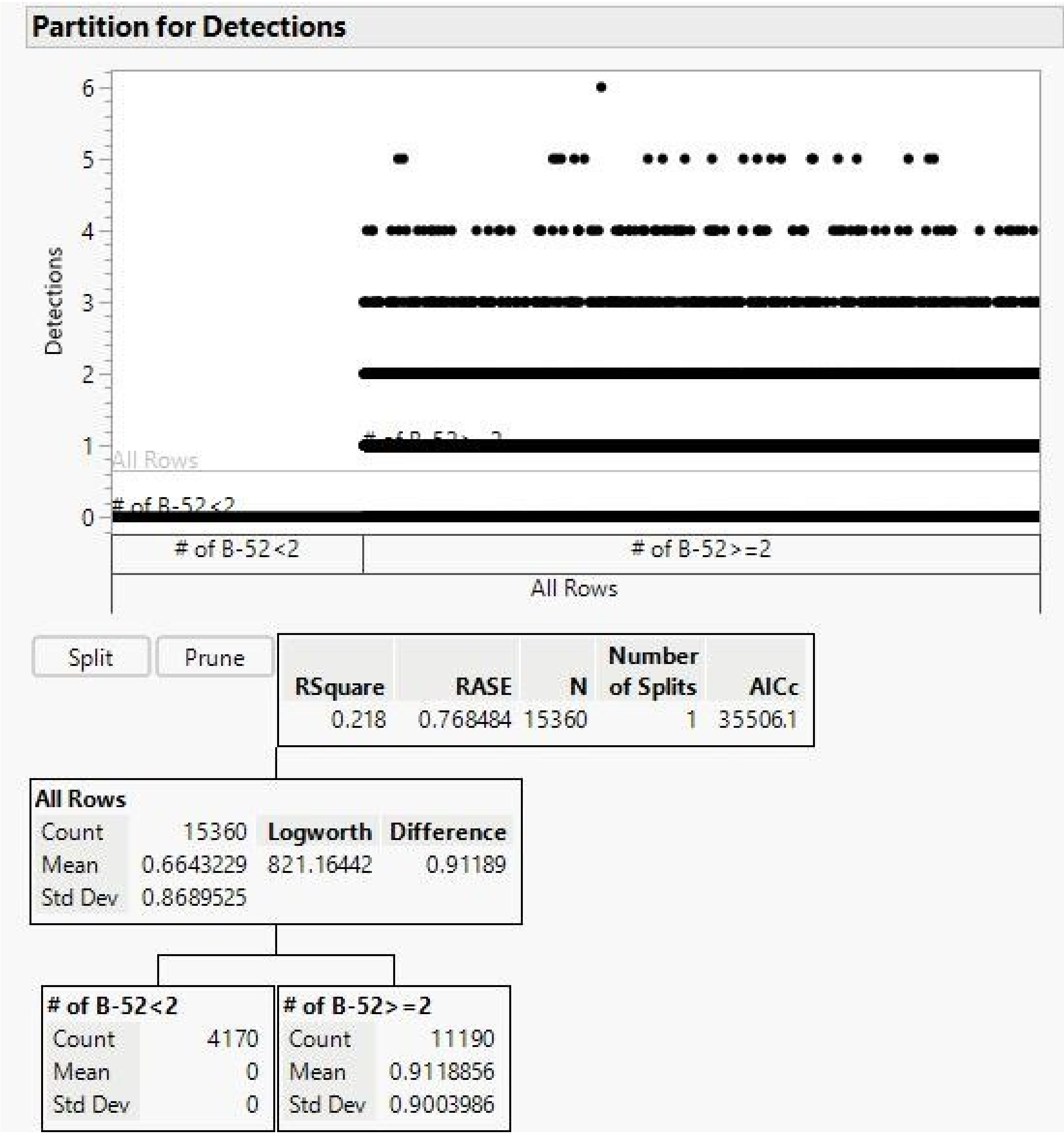


Figure 20. B-52 Detection Partition

B. CONCLUSIONS

Regression analysis was conducted for four different output variables: mines deployed, detections, time detected, and time undetected. Mines deployed describes the total amount of mines delivered per mission with each mission's objective being to deliver 400 mines. Detections illustrate instances in the model in which an asset has been both detected and discerned what mission they are assigned (the deployment of naval mines). A detection also represents a mission failure and the model is designed to remove an asset that has been detected. Time detected is a time stamp assigned to each asset as it is detected and subsequently must exit the model (for example, in a run that takes 500 hours to conduct, a time detected of 450 means that at the 450th hour, the asset was detected at that time). Time undetected is the total time all assets performed their mission and remained in an undetected state. Each variable was examined independently to determine the impact that each of the input variables has on each output variable for each asset type.

1. Individual Asset Conclusions

The first step in analyzing the assets was to look at them independently and see how they are able to contribute to a larger fleet mission. Based on the analysis shown in Section A of this chapter, Team Trogdor derived the following conclusions about individual assets.

a. B-52s Were The Fastest and Most Likely To Be Detected

Figure 21 shows the probability of B-52 detections in relation to the number of B-52s. As the number of B-52 aircraft increase, subsequently, so did the number of detections in the simulation runs. Enemy detection of the deployment of naval mines was categorized as a mission failure and the deployment asset would leave the model. An unexpected result was the detection time decreased as the number of aircraft increased from 2 to 7, with the decreased detection time with 7 aircraft circled in red on Figure 22 and the success of deploying 400 mines circled in red on Figure 23. We concluded this was due to the cargo capacity and the speed of the aircraft. This indicates that, when the opportunity presents itself, more aircraft can be deployed in the accomplishment of the mission. This incurs with it an additional risk. It is not accounted for in this model (and is outlined in Chapter V) but a large formation of aircraft conducting operations in vicinity of territorial waters would arouse more suspicion than one aircraft would. This is something minefield planners and operational commanders have to consider when planning minelaying operations. The speed and cargo capacity of the B-52 are its greatest assets. Its ability to get into and out of its operating area during the transit time of the three sea-borne assets is the primary capability it brings to the fight. That said, based on their very nature, these assets have to travel through open skies which makes them vulnerable to air search radars which are especially present on the coastlines of our peer adversaries. By having to drop mines from altitude, aircraft are especially susceptible to detection especially with the presence of coastal defense radar sites. There is no confusion that if an aircraft is dropping munitions from the back of the aircraft in the middle of the ocean, no good will is intended by that aircraft. However, if hostilities have already commenced, and the mission calls to reseed an existing minefield or if the mines need to be deployed quickly, the B-52 (or other similar aircraft) is available to provide that capability. Fleet commanders and tacticians must carefully consider these things. An additional consideration is that the B-52 cannot deploy the hammerhead mine. This limits them to mine deployment in a maximum of 50 feet of water because they have to deploy the Quickstrike family of mines.

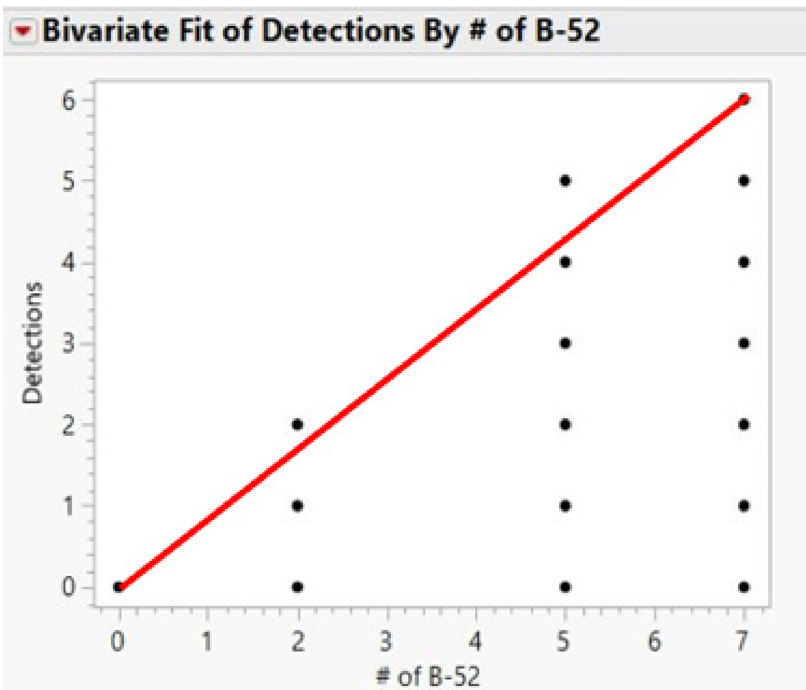


Figure 21. B-52 Detections Based on Aircraft Quantity

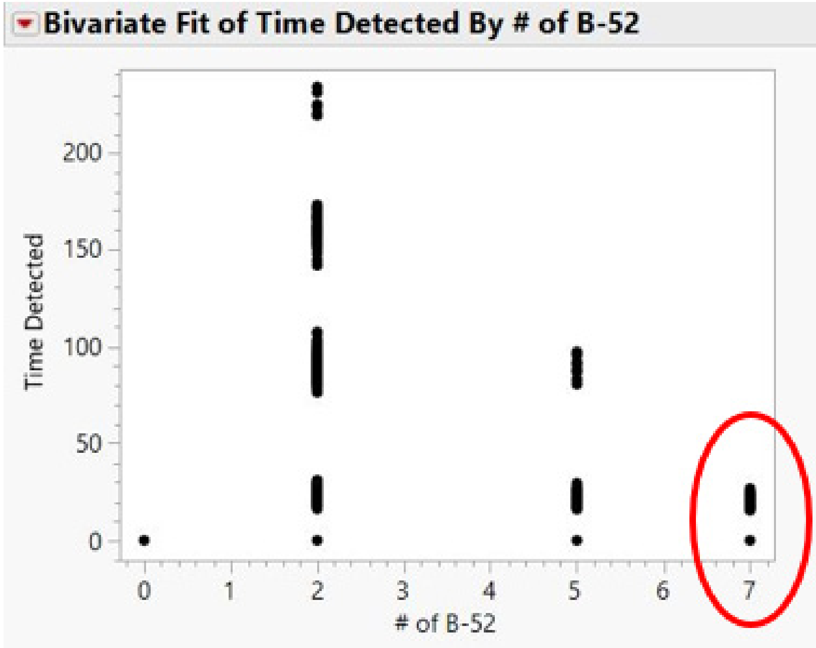


Figure 22. Time B-52 Aircraft in Detected State

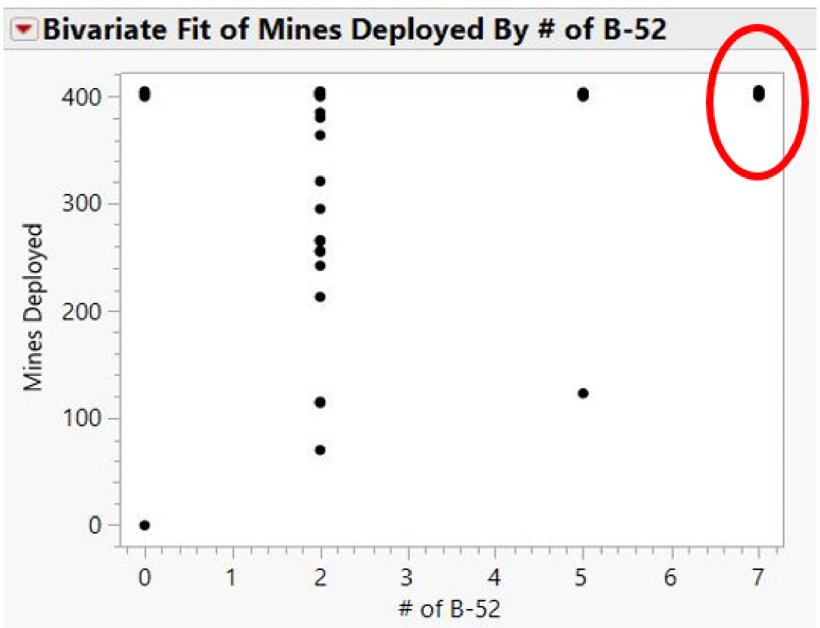


Figure 23. Number of Mines Deployed By B-52

b. Surface Ships Balance Speed and Stealth

Figure 24 is a comparison using the data gathered to illustrate the performance of surface ships across runs. The contour accounts for the number of B-52s, the number of ships, and their P_d while deploying 400 mines. The contour indicates that, with combinations containing only B-52s and ships, the ships remain undetected consistently throughout the runs. The optimized solution based on the data gathered shows that any more than three B-52s will result in detection and mission failure. Compared to ships, if six ships operate without any assistance from B-52s, they are consistently able to accomplish their mission.

There are three main categories of surface combatants in the U.S. Navy's fleet; the Arleigh Burke class destroyer (DDG), the LCS (both Freedom and Independence Variant), and the Ticonderoga class cruiser (CG). These three classes of ships are capable of maximum speeds in excess of 32 knots with the LCS's maximum speed being 42 knots for a short duration. This makes surface combatants faster than subsurface assets (the XLUUV and submarine) and decidedly slower than a B-52. They are also less detectible by radar because their duties are carried out on the surface of the water, giving them an advantage in terms of P_d. Additionally, even if they are detected, unlike the B-52 (or other similar aircraft) it is more difficult to discern what they are doing visually. There is little to no ambiguity in terms of what is occurring when an aircraft is dropping ordnance. A ship can deploy ordnance in a clandestine manner in their own right by changing their aspect (turning to not show the side of the ship that is deploying the ordnance) prolonging their ability to stay on station without hostilities commencing. This and their increased cargo capacity for ordnance makes them a potentially valuable asset in the deployment of naval mines.

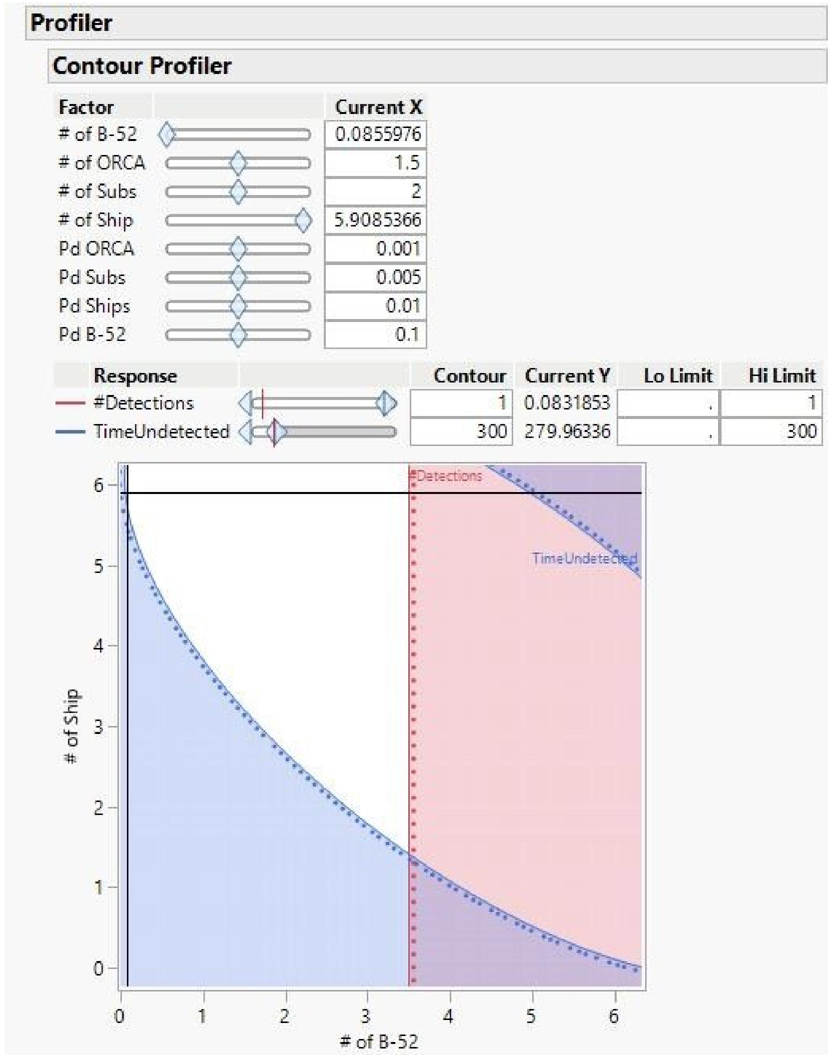


Figure 24. Contour Profile (Ships v. B-52s)

2. Multiple Asset Conclusions

No individual naval asset will be solely assigned a mission to deploy naval mines when the scale of the conflict is warfare with another nation state. With that, Team Trogdor analyzed the combined suitability of assets to accomplish a larger naval mission. Team Trogdor was able to draw the following conclusions based on this endeavor listed below.

a. The Boeing XLUUV Can Be Included In Any Mining Mission With Minimal Risk

Figure 25 illustrates the utility of the XLUUV as a mine deployment asset. This image indicates that during runs including at least one XLUUV, the mission object of deploying 400 mines is accomplished. The silent battery underwater transit of the Boeing XLUUV as well as its submerged nature makes it an invaluable asset, even with its reduced transit speed. During peacetime mine deployment in preparation for hostilities, the XLUUV consistently performs to meet objectives.

Throughout our analyses, the XLUUV provides a consistent presence and reliably remains undetected while deploying the hammerhead mine. Regardless of duration, they provide munitions into their respective operating areas reliably and safely. The additional benefit provided is that they are unmanned and therefore do not put personnel at risk during their mission. While the submarine had all the same attributes as the XLUUV in terms of its P_d with increased performance in their maximum speed, the XLUUV is going to be primarily focused on this effort. A submarine (of any class) will likely not be solely dedicated to a minelaying mission and will be called to perform other duties. However, the XLUUV is solely dedicated to the minelaying effort. The XLUUV also represents decreased personnel cost both in terms of personnel onboard and maintenance personnel.

b. If The Mission Calls For Assets Not To Be Detected, Do Not Include The B-52

Figure 20 is illustrative of the risk associated with deploying naval mines from a B-52 aircraft. The P_d value precludes it from small scale intentionally clandestine missions Because they are likely going to be detected. With their higher P_d value consistently resulting in detections of the B-52, in higher quantities, the resultant detections across runs decreases. This is likely due to both the speed of the B-52 as well as their 101-mine inventory, which indicates that if four B-52s are conducting their mission and do not get detected, they do not take as many runs nor take nearly as long to accomplish their missions.

The B-52 presents an undeniable asset to operational planners. They are able to deliver a payload of 101 mines in a short timeframe. Their transit speed and deployment speed are unmatched by the other assets. They do, however, have a critical factor to include; detection. If the intent is to deploy an inactive minefield during a peacetime setting without commencing or provoking hostilities, then their detection probability potentially precludes the accomplishment of this objective without introducing inherent risk.

c. Probability Of Detection For Ships, XLUUV's, And Submarines Did Not Contribute To Mission Failure

All seagoing assets presented in Team Trogdor's analysis were necessary for mission accomplishment. They consistently accomplished their mission of deploying 400 naval mines. Figure 25, Figure 26, and Figure 27 all show that, at a minimum, one XLUUV, one submarine, and two surface ships (or combinations thereof) reliably achieve their objective of deploying the 400 required mines. The data points on the far left of each figure along the spectrum from zero to 400 mines deployed all indicate instances in which these combinations of assets did not accomplish their objectives. It is worthwhile to note that within Figure 25 through Figure 27, the failures to meet the objective were attributed to detections across all four assets, and the only failure criteria was detection. Those came because of the B-52s higher P_d. To conduct a large-scale operation, commanders need the combined mine-carrying power of all the sea-borne assets to reliably deliver their payload.

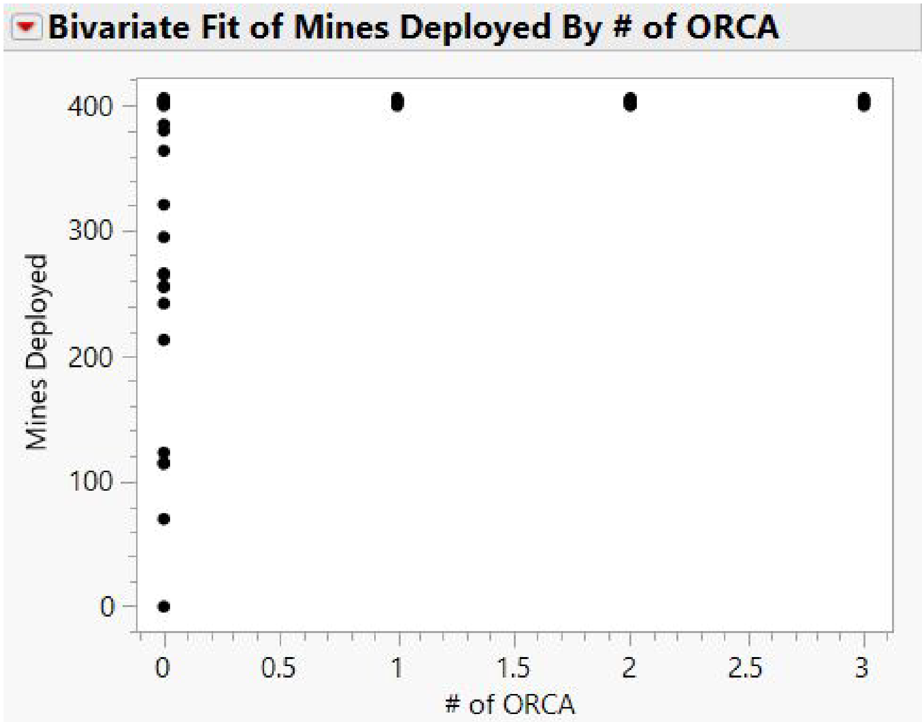


Figure 25. Mine Inventory Deployed Based on Orca Quantity

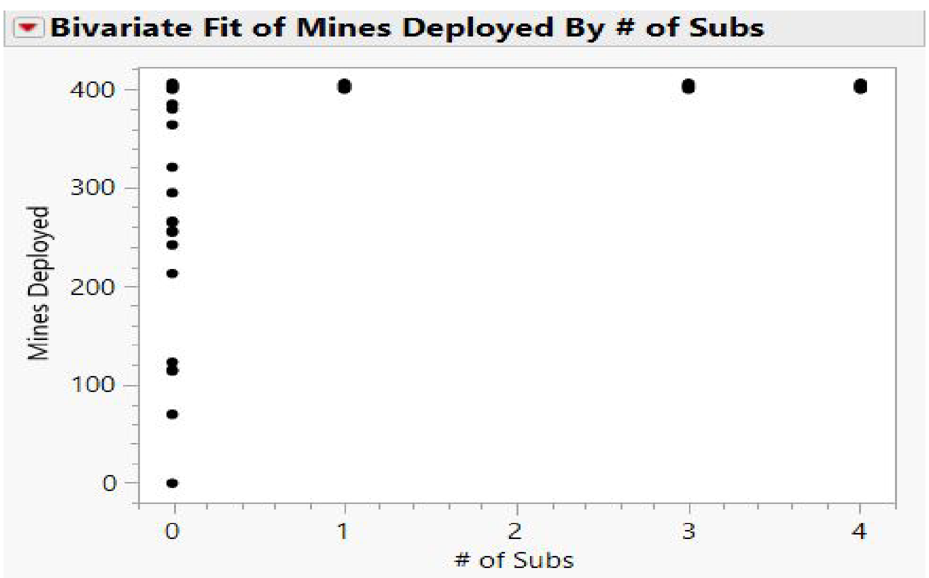


Figure 26. Number of Mines Deployed Based on Submarine Quantity

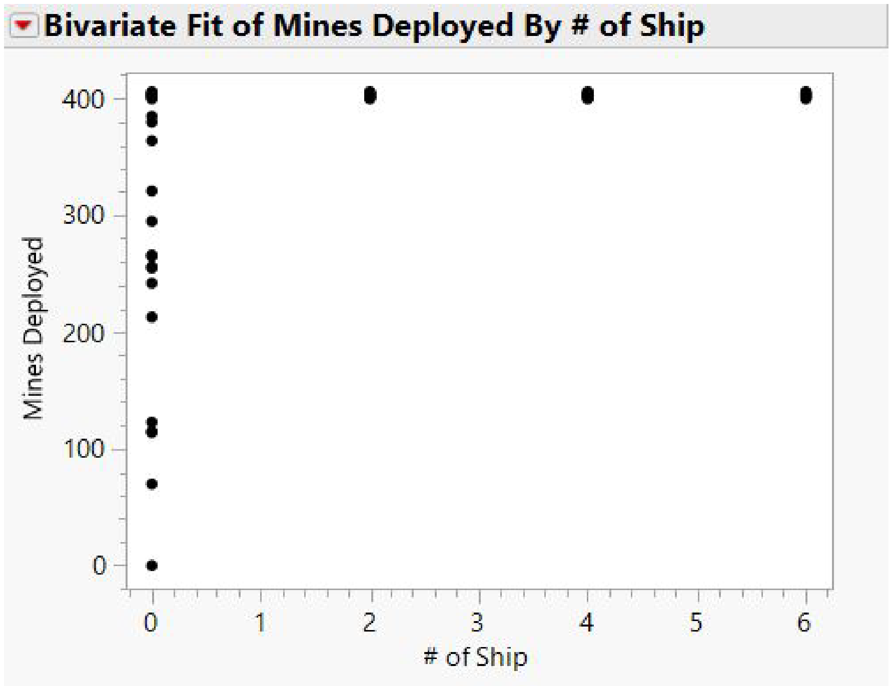


Figure 27. Number of Mines Deployed Based on Ship Quantity

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V. RECOMMENDATIONS AND OPPORTUNITIES FOR FUTURE RESEARCH

A. FLEET RECOMMENDATIONS

The objective of Team Trodgor's analysis was to determine the suitability (or notional suitability) of fleet assets in the deployment of naval mines. Since the Vietnam War, the U.S. has not deployed mines at scale. A recent shift in strategic consciousness has renewed the desire to explore all available means of fleet lethality to contend in the modern maritime battlespace. Team Trogdor assessed the suitability of four fleet assets; namely a submarine, a surface ship, a bomber aircraft, and an XLUUV. Research by any organization does not provide utility unless it is used to inform decisions and provide recommendations. With our analysis comes the following recommendations for those in charge of both fleet acquisitions and the implementation of fleet tactics to consider.

1. Invest in Mining Capabilities for Ships

Despite its speed, the B52 has a higher P_d value than that of any other asset. It additionally cannot deploy the hammerhead mine, the most capable mine in the U.S. Navy's mining arsenal to date. This presents a capability gap that can and will be exploited by a peer adversary that can be mitigated in a manner that is not cost prohibitive. In order to quickly lay mines without the use of the B-52, ships need to be retrofitted with the ability to deploy mines.

2. Train Fleet Operators in Offensive Mining

The U.S. Navy has not conducted offensive mining operations at scale since the Vietnam War. This has allowed the training of fleet operators in offensive mining to atrophy which has bred a distinct lack of knowledge about capabilities and practical application at the deployment asset level. How to plan a minefield, how to assemble mines, how to activate and actuate naval mines are all knowledge gaps at the level that needs it most; the warfighter. Recommendation would be to man, train, and equip Sailors to undertake these missions successfully and confidently.

B. OPPORTUNITIES FOR FUTURE RESEARCH

While Team Trogdor's analysis provides data to inform planning for mine deployment, individual asset suitability in deploying mines, and an assessment of the trade-space between multiple assets, this analysis is merely the beginning of a more complex (and subsequently more accurate) analysis.

1. Classified Input Variables and Considerations

The distance learning medium with which this analysis was conducted limited the scope of the research to open source-available data. This did not allow some of the variables to be entirely accurate (i.e., P_d values). Taking the same model used to illustrate deployment timelines, inputting SECRET-level data would provide more fidelity into the numbers provided. Additionally, in the absence of real-world considerations of conflicting mission requirements, these assets were assigned exclusively to mining missions. Every ship in the Navy is a multi-mission capable platform. Weighing what ordinance would be placed on each ship versus the operating environment is an important part of any commander's decision-making and, subsequently, should be represented as accurately as possible in any effort to model an operating environment. Providing the operational considerations of deployment assets at the appropriate classification level will provide greater accuracy.

2. Modeling of the Physical Environment

Team Trogdor's modeling and simulation assumed that the minefield planners would take the environment into account when planning minefields and provide a high-fidelity plan to operators onboard deployment assets. A real-world naval operating environment would provide items for the deployment asset to contend with (i.e., maneuvering to avoid detection, weather, geography, and underwater topography to name a few). Overlaying this model over a physical environment would simulate these variables for planners to consider. All of these variables would affect both P_d value, deployment time, and transit times. To conduct this type of analysis, it would require simulation software that accounts for terrain like underwater topography, acoustic environment, proximity to shore bases, etc.

3. Compounding Probability of Detection for Larger-Scale Missions

With a large-scale mission comes the requirement for additional fleet assets to meet operational and strategic-level objectives. With that, as more and more assets enter an area, enemy suspicion as to the activity of assets in an area would increase as more time passed and more assets deployed their mines. This model presupposed the initial onset of a mission when determining its P_d and maintained that throughout the simulation when this would likely not be the case. Along with the recommendation of adding SECRET level intelligence into the model, a wargame by the Naval War College to see how this would unfold would benefit this research and refine the analysis.

4. The Platform Variability in the Deployment Assets (Including Stealth Aircraft)

This analysis focused on four specific assets (namely a Virginia-class submarine, a Boeing XLUUV, an LCS, and a B-52 bomber). These assets were chosen based on their likelihood of employment, but the reality of the matter is that multiple assets have to be capable of conducting multiple missions in the complex maritime environment 2023 presents. With that, additional analysis is required to draw adequate conclusions to support operational planning. Varying classes of assets (i.e., including DDGs, stealth bombers, and other submarines) would provide a valuable opportunity for future research.

5. Deployment of Hammerhead Mines From Aircraft

Team Trogdor's simulation categorized its success by the quantity of mines deployed. The analysis relegated the deployment of the hammerhead mine to the sea-going assets (the submarine, surface ship, and XLUUV) and assigned the Quickstrike family of mines to the B-52 bomber. The Quickstrike family of mines were brought into circulation within the U.S. Navy's ordnance in the 1960s and can only be deployed from aircraft and not from surface ships. The ability to quickly deploy a hammerhead mine from aircraft (B-52 or otherwise) would provide additional assets in the hands of operational planners to meet strategic objectives. Exploring this would be of incalculable benefit for future warfighters.

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APPENDIX. JMP DISPLAY DATA

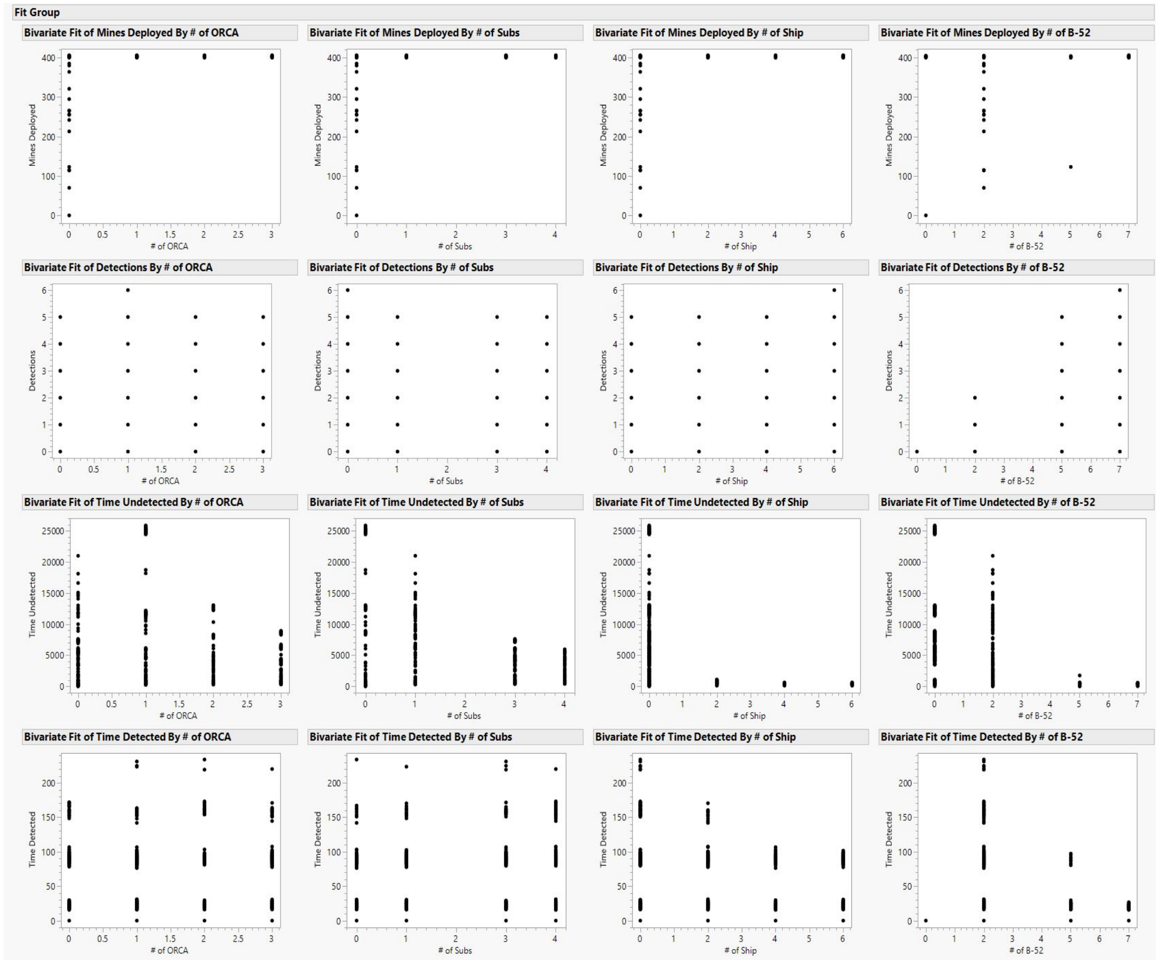

Figure 28. JMP Display Data for All Asset Combinations

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